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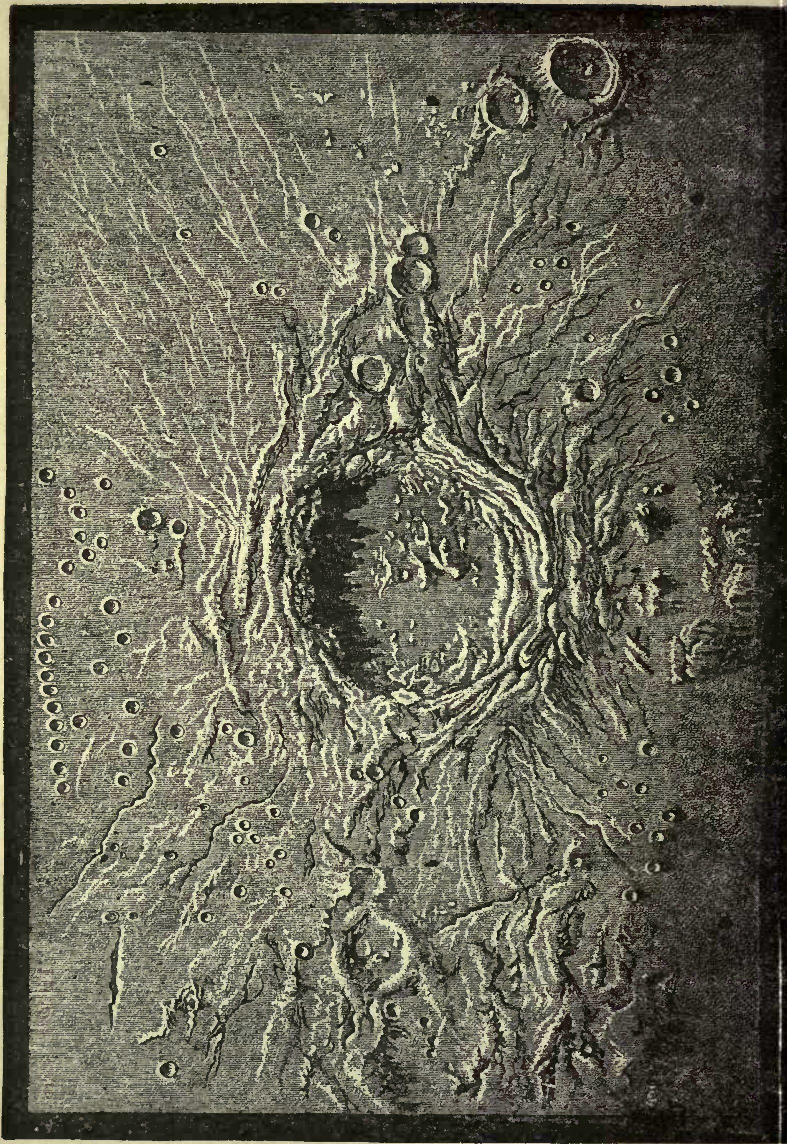
ASTRONOMY.



A Lunar Crater.

Science Primers.

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ASTRONOMY.

BY

J. NORMAN LOCKYER, F.R.S.,

Correspondent of the Institute of France;
Author of Elementary Lessons in Astronomy," &c.

NEW EDITION.

WITH ILLUSTRATIONS.

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Stereotyped Edition.

PREFACE TO THE NEW EDITION.

In writing this little book I endeavoured first, to help the reader, by means of simple experiments, to form true ideas of the motions of the heavenly bodies; and then to give a sketch of the Earth's place in Nature, and of the use made of the heavenly bodies for Geographical purposes.

In the writing I was much aided by my friend, Mr. G. M. Seabroke, of the Temple Observatory, Rugby. In the revision I have been equally assisted by another friend, Miss Mary Browne. To both my acknowledgments are due.

J. N. L.

November, 1883.

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SCIENCE PRIMERS.

ASTRONOMY.

INTRODUCTION.

1. EVERY ONE who is going to read this book knows what a school-room or school-house is. Now suppose it had windows that you could not see through, and that you never went out of it: then you would think, perhaps, that the school house was all the world. But you know better. You know that your school-house is only one house out of many, perhaps in the same street, or at all events in the same parish, whether in the country or the town; most of you even will have walked or ridden into the **Parishes** which lie round the one in which you live.

2. If my reader lives in London he will have done more than this, perhaps, for if he has crossed one of the bridges over the Thames he will have gone from one **County** to another (a county being a collection of parishes as a street is a collection of houses), for

the River Thames divides the counties of Middlesex and Surrey.

3. Just as a county is a collection of parishes, so the **Country** of England, or of Scotland, or of Ireland, or of Wales, is a collection of counties; these four Countries forming the United Kingdom of Great Britain and Ireland. Now wherever you are, whether in a town or village school, whether in the United Kingdom, America, Australia, or India, before you read the next paragraph, write down the

School,
Street,
Parish,
County,
Country,
Kingdom,
in which you are,

and this will show you that your school-house is only a very little speck on the broad lands which together form the United Kingdom, or whatever kingdom you happen to be in.

4. Although you may not have gone to France or Germany you have heard of those places. What are they? Well, the United Kingdom, France, Germany, Russia, Italy, Turkey, and other countries, form the **continent** of Europe, a continent being a collection of countries, as a country is a collection of counties, and as a county is a collection of parishes.

5. You may also have heard of America, Asia,

Africa, and Australia, as well as of Europe; nay, you may even be living in one of these, which, like Europe, are Continents.

6. Now these continents are the largest stretches of dry land on the surface of **The Earth**, the surface being partly water and partly land.

7. I have next to tell you that **the earth, taken as a whole, is a body which astronomers call a planet :** what this is you will learn by and by. Before going further, write down as before, the

School,
Street,
Parish,
County,
Country,
Kingdom,
Continent,
Planet,

in which you are.

8. Some of you may think that I have made a mistake, and am going to write a book on Geography instead of Astronomy. I have not made a mistake. I want to show you that where Astronomy leaves off Geography begins; that just as the shape and size, and position of your school, which is a little speck on the planet on which we dwell, called the earth, can be stated, and just as men by travelling, can find out lands on the earth, far away from your school, and tell us all about them, so are the shape, size, and

position of the earth itself, among all the bodies in the skies, known, and its relation to them can be made clear to you. This is what I have to try to do, and if I can manage to do it, then you will understand better when you come to read about the surface of the earth.

I.—THE EARTH AND ITS MOTIONS.

§ I.—THE EARTH IS ROUND.

9. Now I have said that we are on a planet which we call **The Earth**, but what sort of thing is it? Is it flat or curved, square or round? How are we to find this out? If you look in any direction, if you are in a hilly country, you see hills and valleys; and if you walk over these hills, more hills are generally found rising up, which limit the view to a few miles; if you are in a flat country, the trees and shrubs

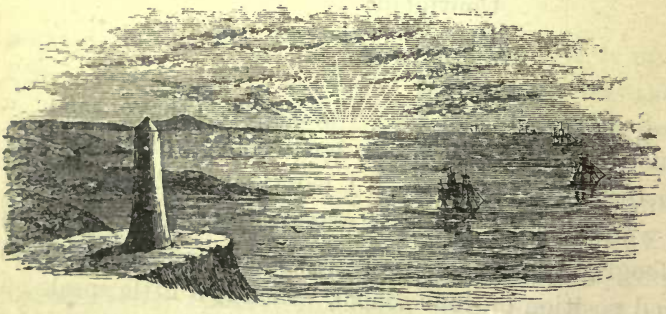

FIG. 1.—How the ships appear and disappear at sea.

appear to meet the sky in every direction around you. We may travel to any place we like, still there is this line where the surface of the earth and the sky meet, so that for aught we could tell to the contrary in this way, the earth might be a nearly flat surface of large extent.

10. But let us try where there are no rocks or trees, where the surface of the earth is unbroken and smooth; **let us try the surface of the sea.** Watch the ships in the distance just coming into view, and you will find that only their masts are visible; as they approach, more and more of the hull appears, until it is quite visible (Fig. 1). Now if you watch a ship going away from you **the hull will disappear first.**

11. Now what does this mean? Let us make an experiment. Get a smooth table on which there are

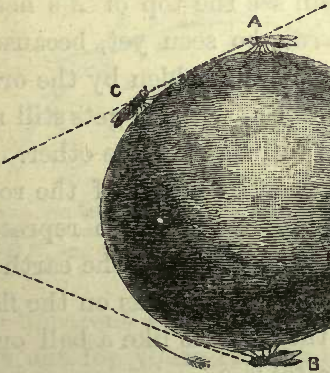

FIG. 2.—Orange with flies.

two flies, let us say, and if the flies are not there, pretend that they are; and suppose them to be moving about. Now it is clear that the flies, as long as they keep on the surface of the table, will always be in full view of each other. They will look smaller to each other when they are furthest apart, and larger when nearer each other; but one part of the fly will not disappear, the other parts being left visible, as in the case of the ships. Therefore the surface of the sea is not flat like the surface of the table.

12. Another experiment. We will take an orange this time, and suppose a fly standing still at the top, say at *A*, Fig. 2, and another fly at the bottom, at *B*. Now it is clear that the flies cannot see each other, because the orange is between them. But suppose *B* moves towards *A*. When it gets to *C*, *A* can just see the top of *B*'s head over the edge of the orange, and *C* can see the top of *A*'s head over the edge. No more can be seen yet, because the other parts of each fly are still hidden by the orange as the whole was before. But when *B* gets still nearer to *A*, each fly will be in full sight of the other.

13. We have then by means of the round orange and the moving flies managed to represent exactly what happens on the surface of the earth with ships, though we could not manage this on the flat table.

14. Therefore the earth is like a ball or an orange, and not flat like a table.

15. You will now easily understand why we see the tops of ships first, and how it is that the higher we

ascend the further we see. We look over the edge of the earth in any case, and the higher we are above the surface, the further away is the edge we look over.

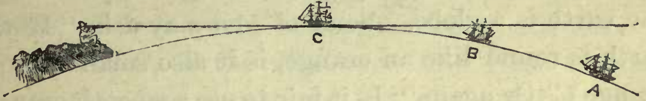

FIG. 3.—Diagram showing how, when we suppose the earth is round, we explain how it is that ships at sea appear as they do. At *A* the ship is invisible, at *B* its topmasts begin to be seen, and at *C* it is in full sight.

16. You must not imagine from this that there is an edge that you can fall over; since the earth is a globe, the apparent edge retreats as you advance. Think this out for yourselves by help of the orange and flies.

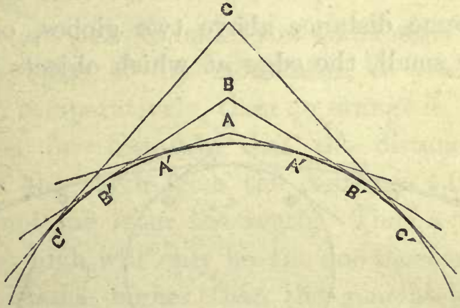

FIG. 4.—Diagram explaining how it is that the higher we go the further we can see. To an eye at *A* the edge is at *A′A′*, to an eye at *B* the edge is at *B′B′*, and so on.

§ II.—THE EARTH IS VERY LARGE.

17. We have employed an orange to prove that the earth is a globe. Some of you may ask, "If the earth is round like an orange, is it also small like an orange?" Or again, "Is it fair to use a smooth orange, while on the earth there are high mountains and all manner of roughnesses? because, though I can believe that the surface of the earth is part of a curve when I look out upon the sea, yet when I see high mountains and deep valleys, I don't understand how such an irregular surface can be spoken of as part of a curve." I must try then to answer these questions.

18. In the first place, it is clear that if you are at the same distance above two globes, one large, the other small, the edge at which objects begin, or cease, to be visible when they are moving to or from the eye, will be further off in the case of the larger globe.

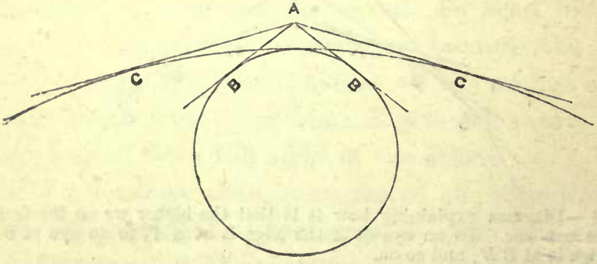

FIG. 5.—Diagram showing that the larger the earth is supposed to be, the further removed from us is the place at which the sky appears to touch the earth.

19. Thus, in Fig. 5, if *A* represent the height of the fly's eye above the orange *B B*, the distance from *A* to *B* would represent the distance of the edge over which the other fly would begin to be visible, while it would be represented by the distance from *A* to *C*, if the flies were on a globe as much larger than an orange, as the circle indicated by *C C* is larger than the circle indicated by *B B*.

20. Now since, when you stand on the sea-shore, you can see some miles out to sea, it must be clear to you that the earth is very large. This, then, answers the first question. The earth is, in fact, some 8,000 miles in diameter: that is to say, a straight line from surface to surface through the centre would be 8,000 miles long.

21. I want next to make you understand that the earth, in spite of its mountains, is really much smoother, comparatively, than an orange is.

Suppose, for instance, that the distance of the surface of the earth from the centre is 4,000 miles, which is not far from the truth. Then a mountain four miles high will only be the one-thousandth part of this distance higher than the general level, and such roughnesses would be included in the thickness of the paper covering a large school globe. You will see at once then that the earth is comparatively much smoother than an orange, for if you were to magnify an orange up to the size of a school globe, it would look very rough indeed.

22. We see then, (1) it is only when the surface is

level, as on a great plain or on the sea, that we can judge by the eye as to the real form of the earth. (2) But even in the most rugged ground the curve is there, though we may fail to notice it. (3) The curve is a very gentle one, because you can see the vessels at sea for many miles before they sink down out of sight. (4) The facts that the curve is so gentle, and that the high mountains make so little difference, show that the circle of which it forms a part is large, and therefore that the earth itself is large; and (5) the earth is so big, that even the highest mountains are in comparison merely like little grains on the surface; its diameter or distance from side to side through its centre is 8,000 miles.

§ III.—THE EARTH IS NOT AT REST.

23. The earth, then, with its surface of land and water, is a great globe, so big that supposing there were a road all round it from your school, and that you were to walk on day and night without rest, at the rate of three miles an hour, it would take you nearly a year to get to school again.

24. The earth, too, hangs in space as you sometimes see a balloon. Now is it at rest? or does it move? Perhaps you will say that it does not move, because your school-house is where it always was; that the houses or trees near to it are no further away or nearer than they were.

25. But this does not help us: let us take a large ball of worsted, or an orange, to represent the earth, and stick into it one pin to represent the school-house, and other pins to picture to you the trees and homes round it.

26. You will see at once that whether the worsted ball or the orange is at rest or in motion, the positions of the pins with regard to each other will not change.

27. How, then, are we to settle the question? **By looking at something not on the earth.** Go out on a clear evening, and look in the **east** (every boy and girl should know where the north, south, east, and west points are): you will see the stars rising higher and higher above the edge of the earth, that is, the line where the earth's surface and the sky meet, which we must henceforth call the **horizon.** Those in the **west** will be gradually disappearing just in the same way; the moon also follows their example. In the day-time we find that the sun rises in the east and sets in the west in exactly the same manner.

28. Here there is proof positive that while the houses and trees on the earth's surface do not move with regard to each other, the sun, stars, and moon, which are not on the earth's surface, do move, or appear to move, with regard to the earth.

29. Now let us think about this. What do we mean when we say that a star or the sun rises and sets? We mean that it is just passing either up or down over the edge of the earth seen from the place

where we are; the sun or star in fact does, or appears to do, just what the ships that we referred to in par. 10 did. The ball of worsted or the orange should make this quite clear. Put it on the middle of a table, and stick a pin into its side, the pin's head to represent your eye. Now imagine yourself to be the sun or a star, and walk round the table as represented in Fig. 6, keeping your eye on a level with the pin; at one point the pin will be seen just rising from the edge of the ball; you are playing the part of a rising sun or star, to your own eye represented by the pin's head; at another point in your journey round the table the pin's head will disappear, and at last will be hidden by the edge of the ball. Here you are playing the part of a setting sun or star, supposing the earth to be at rest.

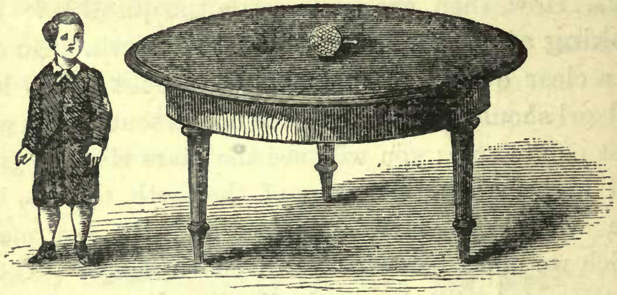

FIG. 6.—Explanation of sun-rise and sun-set, and star-rise and star-set.

30. Now sit down and get some one to turn the ball of worsted round for you in the opposite direction, keeping the pin's head always at the same distance

above the table. In this case, the motion of the ball, while you are at rest, will give rise to the same appearances as those you saw when the ball was at rest, and you walked round it.

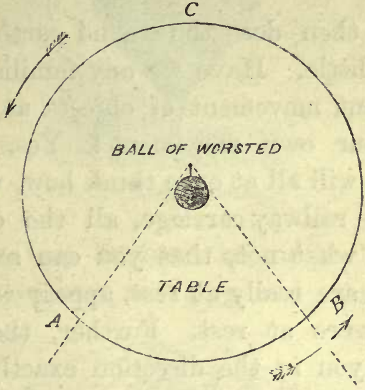

FIG. 7.—Diagram explaining Fig 6 ; with the direction of motion indicated a body at *A* is setting, at *B* is rising, and at *C* is overhead.

31. Hence the appearances connected with the rising and setting of the sun and stars, may be due either to our earth being at rest and the sun and stars travelling round it, or to the earth itself turning round, while the sun and stars are at rest. The ancients thought that the earth was at rest, and that the sun and stars travelled round it. But we now know that it is the earth which moves.

§ IV.—THE EARTH SPINS OR ROTATES LIKE A TOP.

32. You have then to take it as proved that the earth moves, and that the seeming movements of the

sun, moon, and stars, as they travel from east to west, the sun by day, and the moon and stars by night, are not real movements, but are apparent movements only, brought about by the actual movement of the earth.

33. How then does the round earth move? Let us think a little. Have we any familiar example of such apparent movement of objects at rest brought about by our own movement? Yes, certainly we have. You will all at once think how, when you are sitting in a railway-carriage, all the objects, trees, houses and what not, that you can see out of the window and are really at rest, appear to fly past you as if you were at rest. Further, they appear to sweep past you in the direction exactly opposite to the one in which you are going.

34. So far so good. Now will it do to apply this reasoning at once to the earth and stars, to imagine that the whole earth is really moving rapidly from the point that we call West towards the East, and is rushing rapidly past the sun and moon and stars? and that this is the reason they appear to move from East to West?

35. You will at once see that it will not do to reason thus, because we should thus never see the same sun and moon and stars again.

36. How then can we explain the facts? **We can imagine that the earth spins round as a top does,** so that every morning every boy and girl, whether living in England, or America, or Australia,

or India, sees the same sun rise, and every evening sees the same sun set.

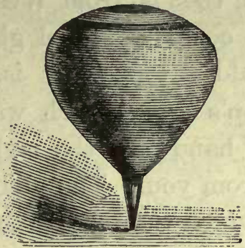

Fig. 8.- A top spinning.

37. It is in fact because the earth does turn in this way that we have morning and evening at all, and day and night are the best proofs that the earth does really spin as I state that it does.

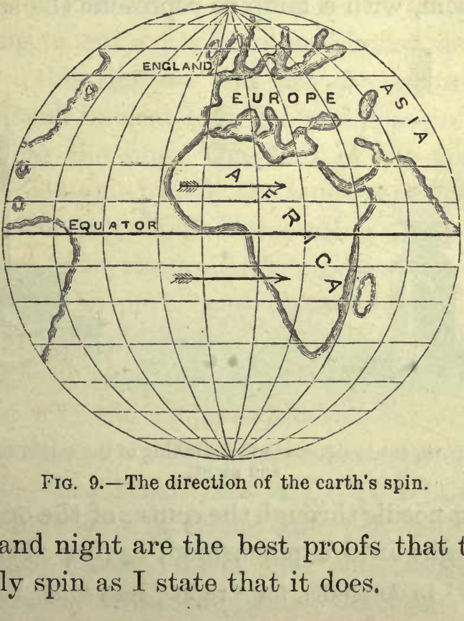
ENGLAND
EUROPE
ASIA
AFRICA
EQUATOR

Fig. 9.—The direction of the earth's spin.

38. And because the sun seems to rise in the East and set in the West, the earth really spins in the opposite direction, that is, from West to East.

39. Now get a common school globe. Set it spinning as you would a top; that is, let the axis be upright as a top's is. Which way is it to turn? With your right [1] hand push the right-hand surface of the globe away from you. The globe then represents the direction in which the real earth turns.

§ V.—THE EARTH ROTATES ONCE IN A DAY.

40. Take an orange, to represent the earth, into a dark room, with a lamp to represent the sun; stick a knitting needle through the centre of the orange, and then upright into a pincushion, having also stuck a

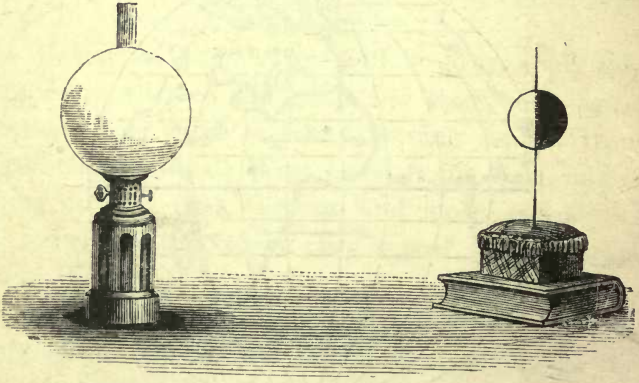

FIG. 10.—Experiment to illustrate the spinning of the earth, as causing day and night.

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[1] In Australia, for "right" read "left."

small pin as far as it will go into the orange, so that its head shall represent an observer on the earth. Twist the needle round, and so make the orange turn round slowly, in the contrary direction to that in which the hands of a watch move, as in Fig. 9.

41. Examine what happens. First, there will be two points on the orange through which the knitting needle passes, which do not move, and these are called the **poles**, the one at the top we will call the **north pole**, and the bottom one the **south pole**, the line joining the poles we will call the **axis**; this is represented by our needle. Draw a circle round the middle of the orange, everywhere at the same distance from the poles, or just where we should cut the peel if we were going to cut a lily or other similar device from the fruit: this line we will call the **equator.** Let the pin's head be near this line and opposite the lamp representing the sun. One half of the orange will, of course, be lighted up by the lamp, representing day, and the other half dark, representing night.

42. Now twist the knitting needle slowly, and you will see that the pin's head, instead of being exactly in the middle of the half of the orange first lit up by the lamp, will, when the orange has turned through a quarter of a circle, be just visible at the edge of the lighted portion; a slight turn more, and no light reaches it—**the lamp has set.** Turn the orange another quarter of a circle, and you find the pin's head in the centre of the dark side, with its head turned exactly from the lamp; another quarter's

turn, and the pin's head is just coming into the lamp-light—**the lamp is rising**; a quarter of a turn more, and the orange has turned round once, and the lamp is again shining directly overhead as at first.

43. The lamp has therefore apparently passed from over the pin's head, set, and risen, and come to the same place again, simply by turning the orange round.

44. So with the earth, it rotates as the orange has done, in the same way, round, not a knitting-needle, but an imaginary axis passing through its poles.

45. Day and night are thus caused, and as the sun appears to take twenty-four hours to move from where it is at any time to the same place again the next day, we learn that the earth actually takes twenty-four hours to turn once on its axis. (Par. 41.)

46. It is time now that we made use again of an ordinary school-globe. Get one of these and place the lamp a few feet from it, on a level with its centre. Let the axis of the globe be upright, and make the globe turn round. Whether it is allowed to remain at rest or is sent spinning round rapidly, the half of it next the lamp will be illuminated, and the other half away from the lamp will be in shade. When it is at rest, the places on one side remain in the light, while those on the opposite side remain in the dark. As you turn it round, each place in succession is brought round to the light, and carried on into the shade again. And while the lamp remains unmoved, the rotation of the globe brings alternate light and darkness to each part of its surface.

47. Now, instead of the little school-globe, imagine the earth, and in place of the feeble lamp, the great sun, and you will see how the rotation or spinning round of the earth on its axis must bring alternate light and darkness to every country.

48. You must not suppose that there is any actual rod passing through the earth to represent our knitting-needle and the steel rod of the school-globe, to form the axis round which it turns. The axis is only an imaginary line, and the two opposite points where it reaches the surface, and where the ends of the rod would come out were the axis an actual visible thing, are still called the **North Pole** and the **South Pole**, both on the globe and on the earth itself.

49. The earth spins then round this axis once in every twenty-four hours. All this time the sun is shining steadily and fixedly in the sky. But only those parts of the earth can catch his light which happen at any moment to be on the side turned towards him. There must always be a bright side and a dark side, just as there was a bright side and a dark side when you placed first the orange and then the globe opposite to the lamp. Now you can easily see that if there were no motion in the earth, half of its surface would never see the light at all; while the other half would never be in darkness. But since it rotates, every part is alternately in sunlight and in darkness. When we are catching the sun's light, we have **Day**; when we are on the dark side, we have **Night.**

50. The sun seems to move from east to west. The real movement of the earth, is, for a reason which has been stated in par. 38, just the reverse of this, viz. from west to east. In the morning we are carried round into the sunlight, which appears in the east. Gradually the sun seems to climb the sky until he appears highest at noon, and gradually he sinks again to set in the west, as the earth in its rotation carries us round once more out of the light. At night we trace the movement of the earth by the way in which the stars one by one rise and set, as the sun rises and sets in the daytime.

§ VI.—THE ROTATION OF THE EARTH IS NOT ITS ONLY MOTION.

51. You are now probably convinced of these facts.

First, that the earth is a globe.

Secondly, that the earth spins like a top.

And lastly, that without this spinning there could be no day and night, so that the regular succession of day and night is caused by this spinning.

52. Here then we have fairly proved that the earth has **one** motion. Now the question comes, has it more than one? How shall we settle this? Well, first of all let us see if this one motion will account for all the things we see.

53. To do this we must again have our lamp and

orange, and imagine them in a room with many pictures on the walls. You wonder what pictures have to do with it? Well, I want the pictures to represent the stars in the sky. There are stars all round the part of space in which the earth and the sun are, only we cannot see them in the daytime, because the sun is so bright. So that if you have pictures all

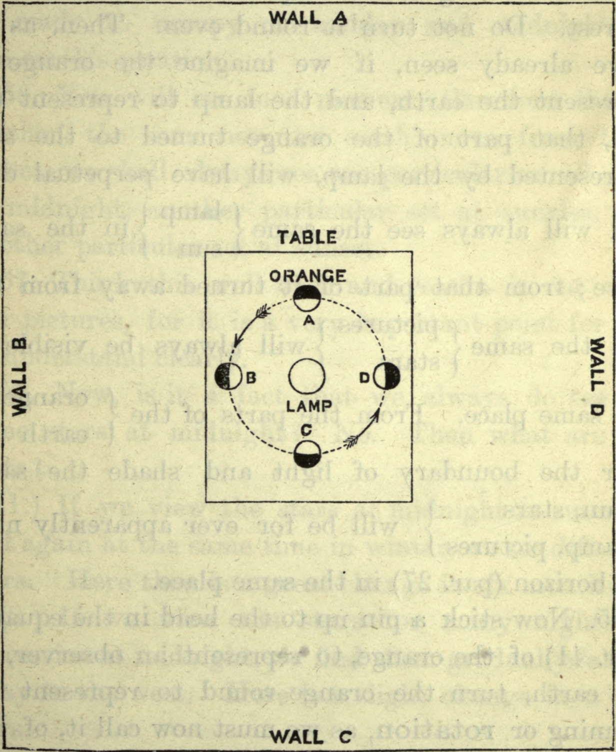

WALL A
WALL B
WALL D
WALL C
TABLE
ORANGE
A
B
D
C
LAMP

FIG. 11.—Explanation of the Earth's motion round the Sun.

round the lamp and orange they will represent the stars. Of course there should be pictures on the ceiling and floor too, but we will content ourselves by imagining them to be there as well.

54. Now imagine the lamp at rest and the orange at rest. Do not turn it round even. Then, as we have already seen, if we imagine the orange to represent the earth, and the lamp to represent the sun, that part of the orange turned to the sun, represented by the lamp, will have perpetual day, and will always see the same $\left\{\begin{matrix}\text{lamp}\\ \text{sun}\end{matrix}\right\}$ in the same place; from that part of it turned away from the sun the same $\left\{\begin{matrix}\text{pictures}\\ \text{stars}\end{matrix}\right\}$ will always be visible in the same place. From the parts of the $\left\{\begin{matrix}\text{orange}\\ \text{earth}\end{matrix}\right\}$ near the boundary of light and shade the same $\left\{\begin{matrix}\text{sun, stars}\\ \text{lamp, pictures}\end{matrix}\right\}$ will be for ever apparently near the horizon (par. 27) in the same place.

55. Now stick a pin up to the head in the equator (par. 41) of the orange, to represent an observer, on the earth, turn the orange round to represent the spinning or **rotation**, as we must now call it, of the earth, and mark that whenever the observer, represented by the pin's head, is in the middle of the lighted-up half, the part exactly opposite is in the middle of the dark half, and that half a turn of the orange brings the pin's head from the middle of the

lighted-up to the middle of the dark portion. Now these two positions—namely, the middle of the lighted-up half and the middle of the dark half—represent nearly enough for our present purpose the position with regard to the sun which an observer is made to occupy at midday and midnight by the earth's rotation.

56. You will see in a moment, therefore, that if neither the sun nor the earth move from their places, we shall always see one particular set of stars at midnight, another particular set at sunrise, and another particular set at sunset.

57. Think this well over and reason it out with the pictures, for it is a very important point for you to understand clearly.

58. Now, is it a fact that we always do see the same stars at midnight? No. Then what are the facts?

(1.) If we view the stars at midnight in summer, and again at the same time in winter, we see different stars. Here then is a great change in six months.

(2.) If we view the stars for many nights in succession at midnight, we find them gradually falling away to the west. Here is a slight change in a few days.

(3.) After the lapse of a year the same stars are visible at midnight.

59. Now **move the orange round the lamp in the same direction as the earth rotates,** and you will see at once that this explains all the facts.

60. In Fig. 11, I have given a drawing of the lamp, orange, table, and room, as you would see them from above. First consider the orange at *A*. Then at midnight the observer on the dark side would see the stars opposite to the sun, the pictures on wall *A*: at *B*, at midnight he would see the stars opposite the sun, now represented by the pictures on wall *B*; and therefore no longer the same stars as were seen before. So on with the positions at *C* and *D*.

61. I must next point out to you that the same effects would be produced as those we see and have thus accounted for, by supposing the sun to travel round the earth in the opposite direction. But we know that the earth really travels round the sun, and not the sun round the earth.

§ VII.—THE EARTH TRAVELS ROUND THE SUN ONCE IN A YEAR.

62. The earth then not only rotates on its axis once a day, but travels round the sun. In this way we have accounted for the fact that as seen at midnight, or at the same hour every night from any part of the earth, whether England, America, Australia, or India, the stars visible are continually changing. We have found also that they change very little in a few nights, very much in six months, and that after twelve months, the same stars again appear in the same places.

63. Now my reader should again go to his lamp and orange, and he will find that precisely as the earth spins in a day, **so it goes round the sun in a year.**

64. For it is clear that if for instance the journey only required six months, then in six months the same stars would be visible at midnight, and so on for any other period you might choose to suggest. Here then we have the origin of the year, which is the time the earth requires to get back to the same place in its path round the sun.

§ VIII.—THE TWO MOTIONS OF THE EARTH ARE NOT IN THE SAME PLANE.

65. "How does the earth travel round the sun? does it jerk, or go up and down, or always smoothly and right on, keeping the same level?" some of you may ask. I answer, the earth travels smoothly, and always keeps the same level; as horses do, galloping round a very level race-course. To picture this more exactly, imagine a very large ocean with the sun and earth floating on it up to their middles, then imagine the earth to travel thus round the sun once a year in a nearly circular path, that is, always keeping about the same distance from the sun.

66. Now get five balls, one larger than the others,

to represent the sun, stick a knitting-needle through each ball and weight the balls, so that they sink up to their middles, and then put them in a tub of water as shown in Fig 12; the knitting-needle will represent the earth's axis.

67. We have now a representation of the sun, and of the earth in four parts of its annual journey. What I want you to understand is that the motion of the earth is not only smooth, but that **its motion is in the same plane**, a plane being a level surface represented by a sheet of cardboard or the surface of the water in the tub: and next that this plane in which the earth moves passes through the centres of the sun and earth, as the centres of the balls will be on a level with the water if you have weighted them properly. Further let me call the plane represented by the level surface of the water **the Plane of the Ecliptic.**

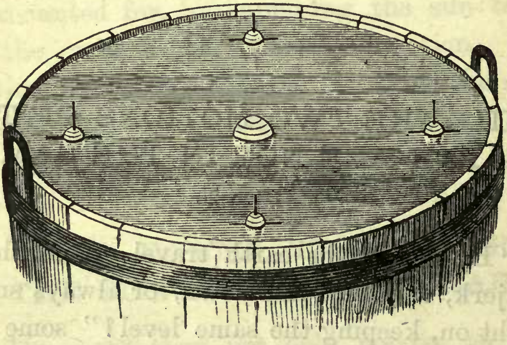


FIG. 12.—The plane of the Ecliptic.

68. Here then is defined the plane of the earth's motion yearly round the sun; this plane of the ecliptic is the earth's race-course. What is the relationship of this to the plane of the earth's daily motion round its axis, or as we call it **the Plane of the Equator?** Let us see.

69. Now it is clear that if the earth's axis is supposed to be upright with regard to the plane of the ecliptic, or to form a "right angle" with it, the plane of the earth's spin will be the same as the plane of the earth's motion round the sun. This is the state of things represented in Fig 12.

70. But are these planes the same? Let us suppose them to be so. Stick a pin into one of the smaller balls, make the ball spin uprightly like a humming top, and it will represent the earth as it travels round the sun, and you will find that on this supposition, the days will always be of the same length, because the boundary of light and darkness would pass through the two poles, so that each part of the earth's surface would be an equal time in the lighted up, and in the

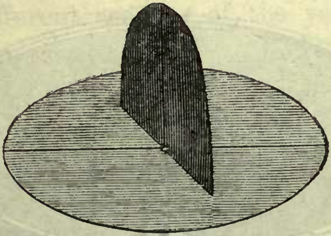


FIG. 13.—Two planes cutting each other at right angles.

dark, half, if the motion of rotation were uniform. But the days are not all of the same length; in winter in England they are short, and the nights are long; and in summer the days are long, and the nights are short; and, further, while it is winter here in England and America it is summer in Australia.

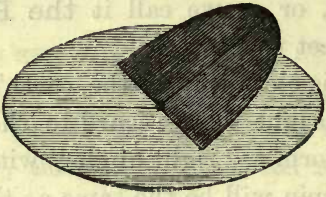


FIG. 14.—Two planes cutting each other obliquely.

71. So then the planes of the two motions cannot be coincident; but we can explain all the facts by assuming them to be inclined to each other as shown in Fig. 14, so that the inclination of the earth's axis in

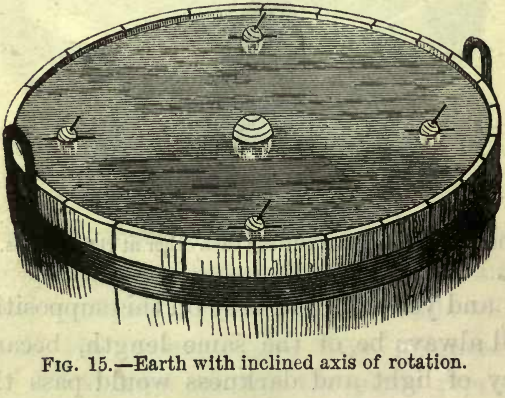


FIG. 15.—Earth with inclined axis of rotation.

its journey round the sun is really represented by the little balls in Fig. 15, in which they no longer spin upright as in Fig. 12, their axes being inclined to the plane of the Ecliptic.

§ IX.—WHY THE DAYS AND NIGHTS ARE UNEQUAL.

72. We can now leave the tub, and come back to the lamp and orange, remembering that the knitting-needle must no longer be upright as we allowed it to be in Fig. 10; and that the plane of the ecliptic is represented by the horizontal plane in which lies the line joining the centre of the lamp and the centre of the orange.

73. We have before accounted for day and night, now let us see if we can explain why they differ in length at different seasons of the year. Place the lamp as before on a table in the middle of the room, and support the orange at the same height as before, inclining **the upper end of the knitting-needle a little way from the lamp.** Let us call the upper pole the north pole.

74. Now turn the orange round, and you will see that the light never shines on the part of the orange near the north pole, and always shines on a part round the south pole, however rapidly you turn the orange; but that, as before, parts near the equator alternately become lighted and darkened. Now stick a pin in the orange, to represent an observer near the north pole,

and again twist the orange, and you will see that he never gets into the light region ; stick it near the south pole, and here he will always see the lamp, so that, with the earth in this position with regard to the sun, to a person at the north pole it is always night, and at the other pole always day.

75. Again stick the pin in the orange, about halfway between the equator and the north pole, and twist the orange, and you will see that, as it travels round with the orange, it has a much longer journey round on the dark side of the orange than it has on the light side. At this point, therefore, the night is much longer than the day, and you will see that the nearer you place the pin to the north pole, the shorter will be its period of illumination, till it gets so far north as never to be illuminated at all.

76. On the other hand, the nearer you place the pin to the equator in the northern half of the orange the longer it is lighted, or the days become longer and the nights shorter, till on the equator the journey in the light is just equal to that in the dark.

77. Exactly the reverse takes place on the south side of the equator; the further you place the pin towards the south pole, the longer will its journeys in the light become, till near the pole it never passes into darkness.

78. Now if you increase the inclination of the knitting-needle away from the lamp, you will see that the days and nights become more and more unequal at any place where you choose to place the pin, except at the

equator, and the less you incline it from the lamp the less is the inequality, so that when it is upright, day and night are equal all over the orange. Now you all know that England is on the north side of the equator, about half-way between the equator and pole, but somewhat nearer the pole than the equator; and you also know that in winter the days are much shorter than the nights, and we at once therefore account for this by supposing the axis of the earth to be tipped in the same manner and direction as that of the orange, so that the orange in the case just mentioned represents the earth in the northern winter.

79. It is, however, not always winter with us, and following winter comes spring, when the days and nights are equal in length on March 22; then comes summer in three months more, when the days are longer than the nights; just the reverse of what happens in winter. In autumn, on September 22, the days and nights are again equal. How can we account for this? Let us consider, and return to our orange; we might try to explain it, by tipping the orange less and less till the axis is upright to represent spring, and then tip it towards the lamp to represent summer, for you will see from what has been said before, that if the north pole be turned away from the lamp, the nights are longer than the days; when it is upright they are equal; and when it is turned towards the lamp, the days are longer than the nights; but the earth's axis does not alter in its direction, as we always find that the axis points very nearly to the

same star, called the pole-star, at all times of the year.

80. We must therefore try another method. Move the orange the contrary way to the hands of a watch, round the lamp, still keeping the axis pointing in the same direction, or more correctly, keeping the axis represented by the knitting-needle always parallel to itself; let it be moved a quarter of the way round the lamp and rotate the orange, and observe the length of day and night as before; you will see that the poles are on the boundary which separates the light from

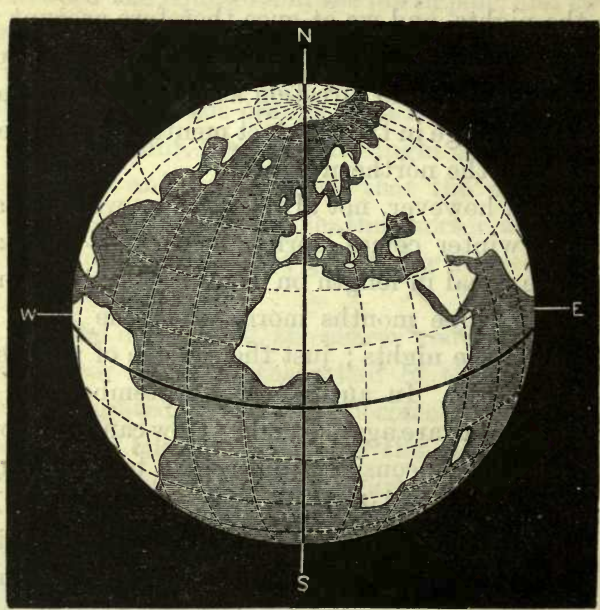


FIG. 16.—The Earth, as seen from the Sun at the Summer Solstice, June 22 (noon at London).

the dark half, and the journey of every part of the orange through light and darkness is equal. This position corresponds to the commencement of spring, March 22.

81. Move the orange another quarter of a circle

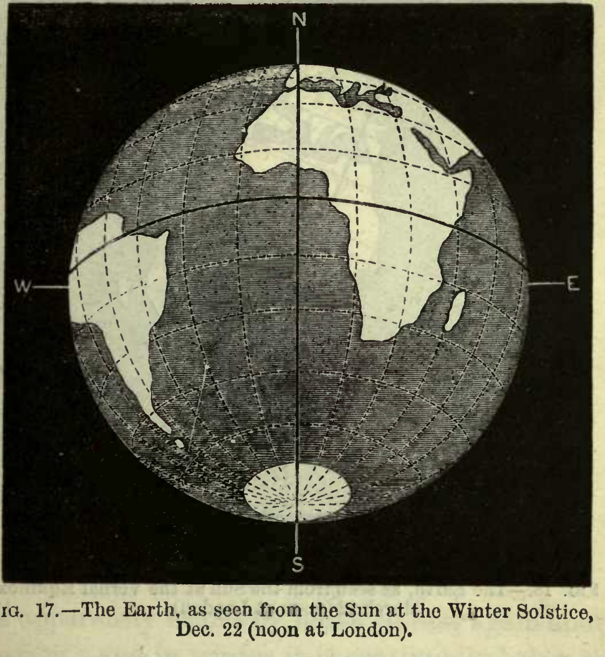


FIG. 17.—The Earth, as seen from the Sun at the Winter Solstice, Dec. 22 (noon at London).

round the lamp; now you see the north pole is tilted towards the lamp; and at every place north of the equator, or in the northern half, or hemisphere, day is longer than night, corresponding to summer, and the reverse at the southern hemisphere; so we have matters just reversed by moving the orange half-way round the lamp.

82. Another quarter's turn, and day and night are again equal, corresponding to autumn, Sept. 22; one more quarter brings the orange to its original position.

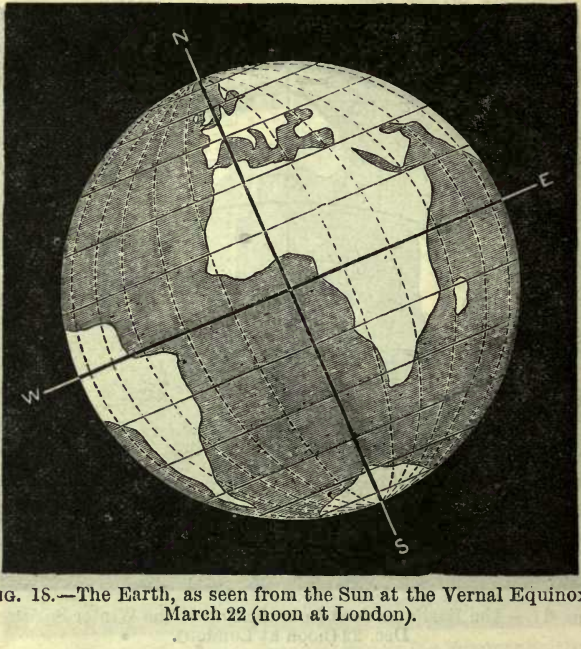


FIG. 18.—The Earth, as seen from the Sun at the Vernal Equinox, March 22 (noon at London).

83. Just in the same way the earth moves round the sun in a year, passing from winter through spring to summer, and through autumn to winter again; the positions of the earth in spring and autumn, when the days and nights are equal, are called the **equinoxes**, that is, the "equal nights."

84. You will also be able to see that during the summer in the northern hemisphere the sun is continually visible above the horizon at places surrounding the north pole; for instead of setting in the west, it goes apparently round by north to east again above the horizon; and in winter it is continually below the horizon, never rising at all. In the southern hemisphere the same thing happens, so at the poles there is a day of six months succeeded by a night of the same length.

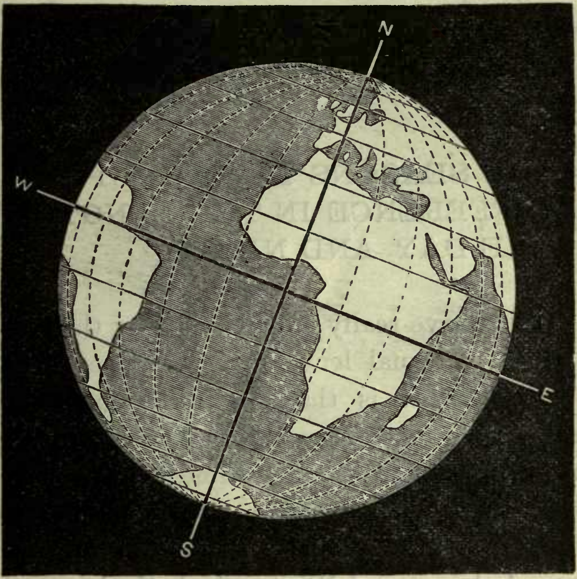


FIG. 19.—The Earth, as seen from the Sun at the Autumnal Equinox, Sept. 22 (noon at London).

85. I have given four drawings of the earth as seen

from the sun in Spring, Summer, Autumn, and Winter. The centre of each diagram represents the point over which the sun is at the different times of the year. Imagine the globe to turn once round in each of these positions, and what I have told you will be much clearer.

§ X.—THE SEASONS DEPEND UPON THE DIFFERENCE IN THE LENGTHS OF THE DAY AND NIGHT.

86. If you have really understood why the day and night are of unequal length you have really understood also how it is that, both in England and Australia there is winter and summer, the English summer happening at the same time as the Australian winter; why in fact **on the earth the seasons change**, and we have the succession of Spring, Summer, Autumn, and Winter, in both the northern and the southern hemisphere (that is, the half of the earth north or south of the equator), and at different times of the year.

87. When the days are long and the nights are short in either the northern or the southern hemisphere, in that hemisphere the sun is visible in every twenty-four hours for a longer period than it is absent, therefore the heat accumulates. On the other hand, when the days are short and the nights are long

in either hemisphere, the sun is absent for a longer time than it is present, so the absence of the heat is more felt.

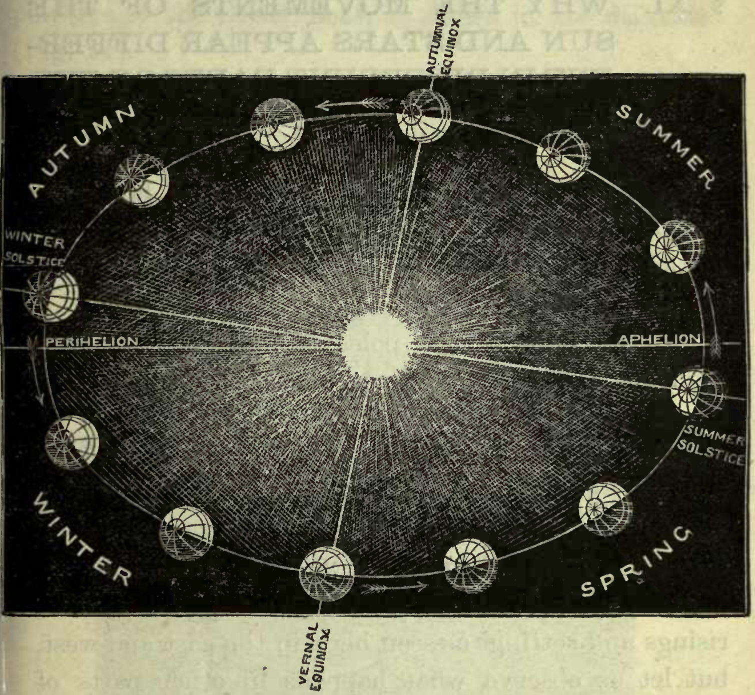

AUTUMNAL EQUINOX
AUTUMN
SUMMER
WINTER SOLSTICE
PERIHELION
APHELION
SUMMER SOLSTICE
WINTER
SPRING
VERNAL EQUINOX

FIG. 20.—Explanation of the Seasons.

88. In spring, although the days and nights are equal as in autumn, the powers of nature are renewed by their winter's rest, so spring is the time of buds, while autumn is the time of decay.

§ XI.—WHY THE MOVEMENTS OF THE SUN AND STARS APPEAR DIFFERENT IN DIFFERENT PARTS OF THE EARTH.

89. I must now endeavour to explain how it is that, as seen from different parts of the earth, the motions of the heavenly bodies appear to be very different.

90. Not only at the poles is there a day and a night of six months, and not only at the equator are the days and nights always equal, but at the poles the stars seem to travel round a point overhead, while at the equator the stars which travel overhead seem to rise and set almost vertically, and not on a slant as they do in England, America, and Australia.

91. We have already become acquainted with risings and settings as seen here, in the east and west, but let us observe what happens in other parts of the sky, and see how they move; you will see that in England the stars near the south rise only a little east of the south, get to the highest point above the horizon exactly south, and set as far west of south as they rose east of it. Those that we at first see rising in the east, pass over the south much higher above the horizon, and set in the west again. The stars near the north neither rise nor set, never going

below the horizon, but moving in circles round a point in the heavens, marked by a star called the **pole star,** a star easily found by its being in a line with the pointers of the Great Bear, as shown in the diagram (Fig. 21).

92. Now, to illustrate this, take a small globe, make its axis upright, and in order to indicate the horizon

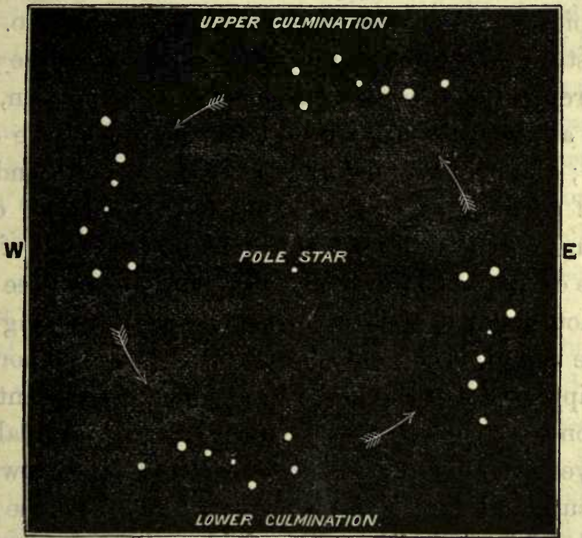


FIG. 21.—The Pole Star and the Constellation of the Great Bear, in four different positions, after intervals of six hours, showing how the Great Bear appears to travel round the Pole Star.

of any place quite plainly, cut a piece of card about the size of a penny and gum the centre of it on the globe as near the upper axis or north pole as the mounting will permit, or put it on the axis if you can ;

then a person standing at or near the pole would be able to see everything above the card, but not below —in fact, the edge of the card represents the horizon. Now spin the globe to represent the motion of the earth, and watch what the appearance of the stars represented by the pictures on the walls (Par. 53) would be to a person standing at the pole. You will at once see that the card simply turns round like a wheel, and the pictures that were above it at first remain so. So the stars would not rise or set to a person at the pole, but remain at the same height above the horizon, and only apparently move round the points of the compass; the pole star being of course overhead, and the stars turning in circles round it. If you fix on a picture on the walls below the plane (Art. 67) of the piece of paper to represent the sun, you will see you cannot make it appear to rise or set by turning the globe round, it can only be thrown above the horizon by tipping down the globe as is done to represent the seasons. Now you will recollect that for one half of the year the north pole of the earth is tipped towards the sun, and during the other half away from the sun, so that it can only have day during the summer half of the year, and night during all the winter; and if you will look at Fig. 20 you will see that during the summer the small circle round the pole is lighted, so that there is no night there as the earth turns round, and in winter for the same reason there is no day, but in spring and autumn half the circle is light and half dark, so that every place is brought by the turning of the earth into daylight and back into night every twenty-four hours.

93. So much then for the view of the heavens at the pole. Now let us examine what takes place at the equator. To do this, gum the disc of card on the equator, and turn the globe. You will see that it no longer turns like a wheel, but turns somewhat as a penny does when spun on its edge; and on turning the globe half-way round, an entirely new set of stars appears above the horizon, represented by the edge of the card, the two places in the heavens pointed to by the poles of the globe will be just on the horizon, the north pole-star just on the northern part of the horizon, and the south pole just on the southern part of the horizon, and the stars which rise due east will pass exactly over the paper, and set due west as the globe is turned.

94. If you fix on one picture to represent the sun, you will see that the globe can be just turned half-way round while the sun, or the picture representing it, is above the paper horizon, and half-way round while it is below it; and as the earth turns round once every twenty-four hours, the sun will be twelve hours above and twelve below the horizon, so the days and nights at the equator are always of equal length, and by tilting the globe to represent the changes of seasons you will find that the length of a day or night remains unaltered at the equator.

95. Now try for yourself, and place the card in other positions on the globe, beginning at the equator

and going up to the north pole, and watch the gradual change in the apparent movements of the stars in rising and setting.

96. All that has been said refers to the apparent motions of the stars as seen on the equator, or to the north of it; so, in order to examine the apparent motions of the stars visible in the southern hemisphere, you must stick the card at different places south of the equator of the globe, and turn the globe and observe what takes place. First place it between the equator and south pole, to represent the position of an observer in Australia, then the equator will be north of him instead of south, and his pole south instead of north, as in our hemisphere, and if he looks towards the north he will see exactly the same rising and setting of the stars as he would in the northern hemisphere; but his right hand will be towards the east and his left towards the west, so that the stars will rise on his right hand and set on his left, traversing the heavens in an exactly opposite direction to that they take in the northern hemisphere. Further, he will see near the northern horizon the stars seen in England near the southern horizon, the northern stars being altogether invisible to him.

97. In order to make the apparent movements of the stars visible in the southern hemisphere more plain, call the upper pole of the globe south, and the lower north, and turn the globe contrary to the way in which you turned it before; for the earth appears

to rotate in a different direction according to the position from which it is viewed, like the hands of a watch, for they go in one direction if looked at on the face, and in the contrary direction if looked at from the back, supposing the watch to be transparent; so to an observer in the southern hemisphere looking towards the equator, as we supposed the observer in the northern hemisphere to do, the earth appears to rotate in the opposite direction to that seen from the northern hemisphere; and consequently, if we make the south pole the uppermost, we must reverse "right" and "left" for all the motions including its motion round the sun.

98. When you have done this, bring the true south pole of the globe to the top, and then experiment with the paper horizon as before.

99. On the globe you will probably find a "wooden horizon," this represents the horizon of the centre of the earth, as we have supposed the circumference of the card disc to represent the horizon of a place. The wooden horizon really represents the true horizon of the place at the top of the globe for the time being.

II.—THE MOON AND ITS MOTIONS.

§ I.—THE MOON TRAVELS AMONG THE STARS.

100. You have now become acquainted with the form of the earth and with its motions, first its spin or rotation round its own axis in twenty-four hours, and secondly its movement round the sun, which it accomplishes in a year.

101. We have also seen how these two real movements of the earth give rise to two apparent motions of the sun and stars, the daily movement of rising and setting, and the yearly movement by virtue of which, month after month, we see different stars in the south at the same time in the evening, until, after the expiration of a year, the grand procession begins afresh. The "Physical Geography Primer" will teach you what the earth is like—that it is a cool body surrounded with an atmosphere set in motion by the sun's heat.

102. Some of my readers will wonder why as yet I have said nothing of the moon, which appears to us almost as large as the sun, and which sometimes throws such a strong light on the earth.

103. It is now the moon's turn. Look at it some fine evening, and notice its position amongst the neighbouring stars; it is difficult to see small stars near

it, so it is best to take an opportunity when it is near a large one. Observe it again some hours afterwards, or, if need be, on the following evening; you will at once see that it no longer occupies the same position among the stars, but that it has moved among them considerably towards the east. It will be observed to rise later and later every day, by three quarters of an hour to an hour, as is easily noticed by timing its rising for a few successive days. It keeps on losing, as it were, on the sun, till, from being seen at sunset, it does not rise till just before the sun in the morning. After this, the sun apparently passes it, and a few evenings afterwards it is again seen in the west just after sunset, only to lose on the sun and be overtaken again every $27\frac{1}{3}$ days as before, in the same manner as the hour hand of a clock is overtaken and passed by the minute hand.

104. We have now made our observations: let us see how they can be explained. We must return to our orange and lamp, and, in addition, shall require a small ball to represent the moon. Now keep the orange, representing the earth, still, and move the small ball representing the moon in a circle round it, as the earth moves round the sun.

105. We have to see if this motion will account for our observations. First, let the moon be at *E* (Fig. 22), in a line with the sun, and as in such a position it would clearly appear to us to be in the sky near the sun, then it will appear to rise and set at the same time as the sun does, and on twisting the

earth round on its knitting-needle, this will at once be clear. Next move the moon to *T*, to represent its position a few days later; you will now see that the sun will set some time before the moon, for to a person at *A* the sun is just set, but the moon is above the horizon. Again, move the moon to *F*, and you will see it is just south of the observer at *A*, when the sun has set, so that it has lost about six hours on the sun. Move it further on to *G*, and it will just be rising when the sun is setting, and will be south at midnight, having lost twelve hours on the sun, as will be seen, supposing an observer to be at *D*; move the moon further to *H*, then to the observer at *A*, to whom the sun has just set, the moon will not have risen; having lost eighteen hours on the sun, it will rise at midnight, as seen by the

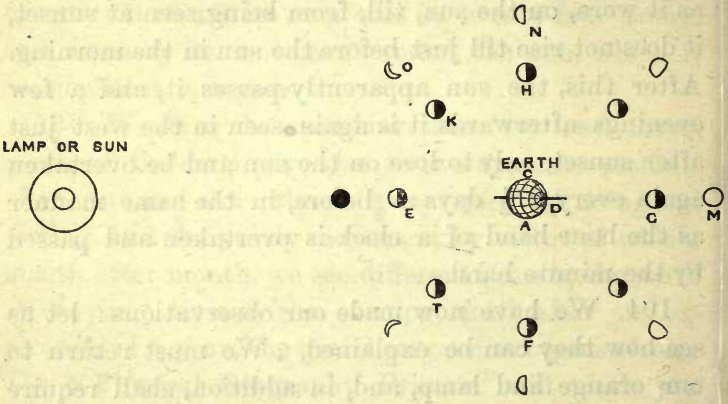


FIG. 22.—The Moon's motion round the Earth.

observer at *D*. To the observer at *C*, the moon is southing and the sun is rising; move it on further to *K*, it will nearly have lost a whole revolution on the sun, and will rise about twenty-one hours after it, if we reckon from the time they both rose together (or three hours before it, if we reckon the other way), and in two or three more days they will both rise together again. Now it is clear from what we have seen that its losing on the sun may be accounted for by supposing it to travel round the earth in about 27⅓ days. And this we know to be the case.

§ II.—THE MOON CHANGES HER FORM.

106. We have thus explained the moon's own motion among the stars, but something else happens to her: as she moves round us, she changes her form from a crescent to a circle. These changes have become so familiar to us, having heard of the changes of the moon as far back as we can remember, that we are apt to look on them as a matter of course, without inquiring into their cause. Let us ask the question, "Does the moon really change?" **No, it is always there, but of the illuminated half a portion only is sometimes visible to us.**

107. Observe the moon some evening; suppose you see it at the "full moon" as it is called, when it

appears round, like the sun: observe whereabouts it is in the sky, and you will find that it is on the opposite side of the earth to the sun, and that it consequently rises at sunset and sets at sunrise, in fact it is in position *G* (Fig. 22); now place the ball representing the moon at *G* on the opposite side of the orange to the sun, then the half of the ball, which is white in the diagram, will be illuminated by the sun, and the other half, opposite to it, will, of course, be dark, in the same manner as we have night when the sun is shining on the other side of the earth to us, and if you place your eye near the orange, you will see all the bright portion and none of the dark side; it is then full moon, and this appearance is represented by the white circle *M*. So that it is now clear that at full moon the moon is on the opposite side of the earth to the sun, and we see therefore the bright side.

108. After the full, the moon rises, as we have seen, later and later after sunset, and we will suppose you observe it a week after the "full." It will rise, as you will find, about midnight. Rather late, you say, to sit up, but the day of astronomers is other people's night. The moon now is no longer apparently round, only half of it is visible. Return to the diagram: in what position is the moon if it rises at midnight? It is midnight to an observer at *D*, and the moon to be rising must be at *H*. Place the ball, therefore, at *H*, and the eye at *D*; now the part, white in the diagram, is the bright

half illuminated by the sun; but in this position the whole of it is not visible, but only half of it and half of the dark portion, you will therefore see that we ought to have the appearance of half moon, *N*, in this case, which we do in reality.

109. Let us continue our observations. If it is too late to sit up after midnight, try and get up before sunrise, and you will see that, as the moon is apparently overtaken by the sun, it will get more and more crescent shaped, and when at *K* it appears as at *O*, till it is lost in the sun's rays when it comes to position *E*. How ought it to appear now? Place the ball between the eye and the lamp, and you will see that the whole of the bright portion is quite invisible. It is "new moon"; look at it a few days after, when it will be visible just after sunset. It will appear in a thin crescent, and will be in the position marked *T* in the diagram. Place the ball in this position, and by placing your eye close to the orange you will see just a crescent of the bright half, and a large portion of the dark half.

110. As the moon appears to get further and further from the sun and to set later and later, more and more of the bright half will be seen, till we get to half moon in position *F*. It is now south at sunset. Place the ball in this position, and your eye close to the orange, and you will see the observation is accounted for. Another week more and the moon again becomes full, and opposite the sun.

111. All these observations may be thoroughly

mastered by standing at a distance from the lamp, or gaslight, which should be the only one in the room, and moving an orange, or ball, round your head, when all the changes of the moon will be rendered clear to you. **The moon, therefore, revolves round the earth in the same manner as the earth goes round the sun, passing from full moon to full moon in about twenty-nine and a half days,** although the moon really revolves around the earth in 27⅓ days, as we have already seen, Art. 103.

III.—HOW THE MOON CAUSES ECLIPSES.

112. From what we have seen, you might think that the moon ought to pass between us and the sun every month, and produce what is called **a total eclipse of the sun**; but, for reasons of which we shall presently speak, it sometimes passes a little above the sun, and at others a little below, when there is no eclipse at all; or it passes over a part only of the sun, and so only covers a portion of the sun's disk from our view, producing what is called a **partial eclipse.**

113. Let us see if we can make matters clear with the use of our orange and ball.

114. Set the lamp on the table, and stick the knitting-needle supporting the orange into a large

pincushion at some distance from it; then take the small ball representing the moon and suspend it by a string so that you can move it round the earth (Fig. 23) without the fingers casting a shadow on it. Now bring the moon between the sun and earth, holding it near the earth as at *C* (Fig. 23), so that the shadow of the moon falls on the earth: wherever this shadow falls on the earth there will the sun be invisible, and there will be a **total eclipse** at that place. At other places on the earth, as at *B*, which the darkest part of the shadow does not reach, the whole of the sun will not be covered by the moon. Here, then, we shall have only a partial eclipse, and the further you go from this region the more of the sun will be visible, so that round the total shadow is another kind of half shade, called the **penumbra,**

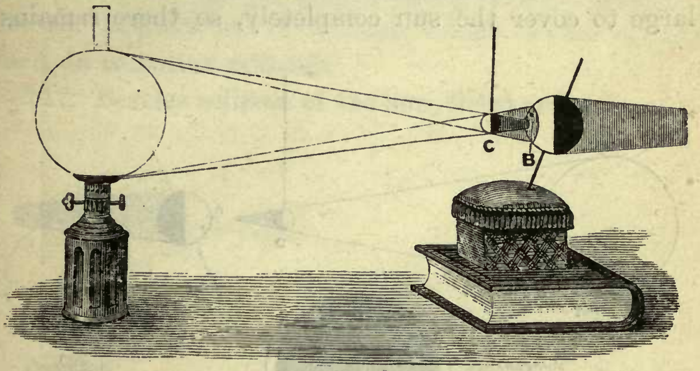


FIG. 23.—Total Eclipse of the Sun.

and, as we have seen, all places in the penumbra will see a partial eclipse only.

115. Now move the moon further away from the earth, to say *D* (Fig. 24), and you will see that the shadow of the moon is not sufficiently long to reach the earth, so there can be no total eclipse, the moon being so far away that its disk is not sufficiently large to cover the sun completely, so there remains the outside edge of the sun visible; this sort of eclipse is called an **annular eclipse.**

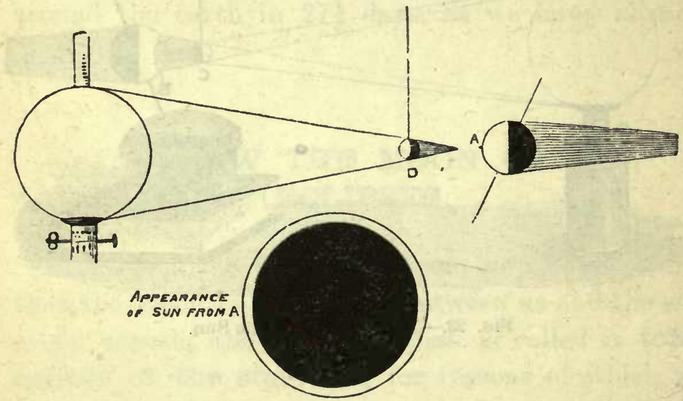


FIG. 24.—Annular Eclipse of the Sun.

116. All this will be clearer if the orange be removed and the eye placed in its stead. First place your eye where the shadow was (Fig. 24), that is, in the umbra of the moon, and you will see a total eclipse. Then move the eye a little lower, still keeping the moon in the same place, and you will see

a crescent of the sun, in fact a partial eclipse, and the further you move your eye from it, the more of the sun you will be able to see. Now place the eye at *A* and so see a total eclipse, and move the moon gradually away from you, and you will see the moon apparently getting smaller, so that at *D* (Fig. 24) it is no longer large enough to cover the sun, and you see the bright edge of the sun round the moon; in fact, an **annular eclipse.**

117. Besides eclipses of the sun, there are **eclipses of the moon,** occasioned by the moon passing through the shadow of the earth. You will readily understand how these happen by placing the lamp and orange as before: on passing the ball representing the moon round on the opposite side of the earth to the sun, it will go into and through the shadow of the earth, and will be darkened, not, as in the case of an eclipse of the sun, by an opaque body coming between us and the sun, but by its being shaded by our earth (Fig. 25).

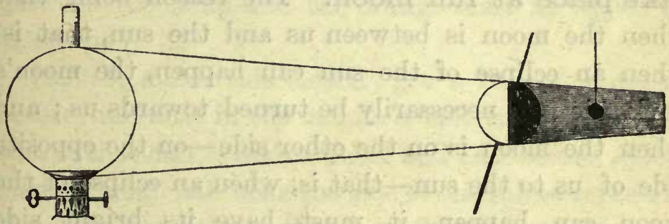


Fig. 25.—Eclipse of the Moon.

118. To an observer on the moon during a total eclipse of the sun, the earth would appear to have a black spot on it, moving rapidly across it; and surrounding the spot would be a circle of half shade the penumbra, in which a partial eclipse is seen from the earth; but in the case of a total eclipse of the moon, the shadow of the earth entirely envelops the moon.

119. You will have understood by this time that an **eclipse of the sun can only take place at new moon, and an eclipse of the moon can only take place at full moon.** The reason being that when the moon is between us and the sun, that is, when an eclipse of the sun can happen, the moon's dark side will necessarily be turned towards us; and when the moon is on the other side—on the opposite side of us to the sun—that is, when an eclipse of the moon can happen, it must have its bright side towards us.

120. We have spoken (Art. 112) of the moon passing sometimes above, and at other times below, the line joining the earth and sun, and, as you will see by referring to the orange and ball, an eclipse of the sun and another of the moon must happen every month if the moon did not so pass.

121. Let us see how we can account for the fact that the moon does thus pass sometimes above and sometimes below the sun, thus preventing monthly eclipses. We have found that the moon revolves round the earth in nearly a circle (with the earth at the centre)

called its **orbit** or path. Let us represent this orbit by a piece of wire, bent in a circle round the orange, and let the moon be represented by a large bead or a small ball strung on it. Hold the ring of wire so that the earth (orange) is in the centre, and move the moon on the wire round it, and you will find that if the ring is held horizontally the moon will pass between the earth and sun, represented as usual by the lamp, at every revolution. Now this we have observed is not the case with the real moon, and, in order to make the bead pass above or below, the part of the ring between the lamp and the orange must be tipped up or down.

122. To make this clearer, get a tub of water as before, and float in the middle a ball to represent the sun, so that half is above water and half below. Float another small ball near the side of the tub to represent the earth, then the earth can be floated round the sun, to represent its annual path. Now, as its orbit will lie on the surface of the water, this surface, as we have seen before (Art. 67), represents the **plane of the ecliptic.**

123. But we have already suspected that the moon's orbit is inclined to this plane, so that at certain times no eclipse takes place; and if we take the wire ring, as before, to represent the moon's orbit, and place it round the earth, dipping one half of the ring below the surface of the water, and keeping the other above, as represented in Fig. 26, where the full line indicates the part above water and the dotted line the part

below, we represent the inclination of the moon's orbit to the plane of the ecliptic, and the line joining the points where the orbit cuts this plane is called the **line of nodes**, and *B* and *D* are the nodes.

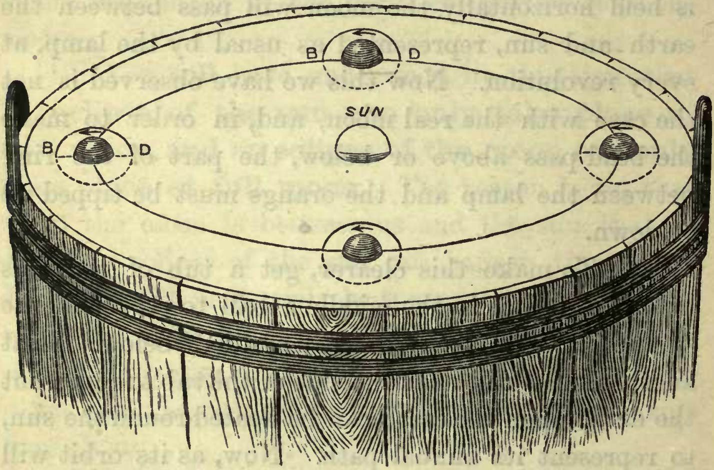


FIG. 26.—Showing the inclination of the Moon's orbit to the plane of the ecliptic.

124. This will render it clear that eclipses, supposing the orbit of the moon to be inclined to the plane of the ecliptic, could only happen when the moon is at the part of its orbit near a node when she comes in a line with the earth and sun, for only then does she in her revolution pass between the sun and the earth. At the other parts of the orbit there can be no eclipse, because the bead on the ring would at its nearest approach to an eclipse be below or above the

water, and not on its surface in a line with sun and earth. And as eclipses do not happen every month we know that the moon's orbit is inclined as we have supposed it to be.

125. We have seen before that the plane of the earth's motion round its axis is inclined to the plane of the ecliptic, and we now find that the plane of the moon's motion round the earth is inclined to the same plane. We should now endeavour to understand how the amount of inclination is fixed in each case.

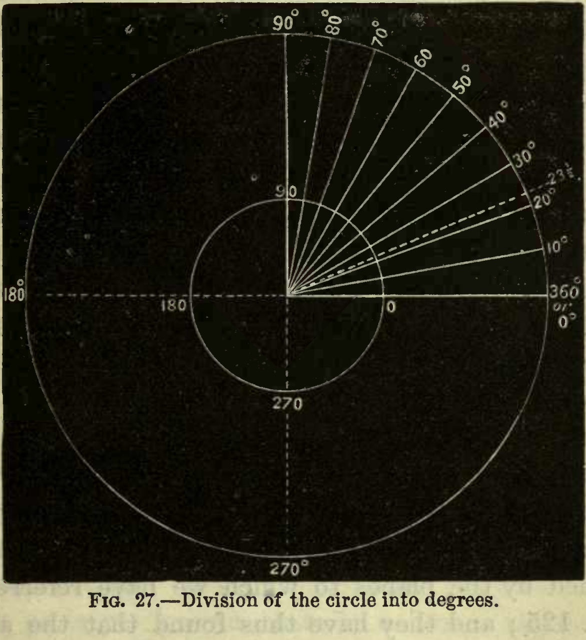


Fig. 27.—Division of the circle into degrees.

126. To do this astronomers divide all circles,

whether large or small, into 360 degrees (written 360°) (see Fig. 27), and if we draw two lines from the centre of a circle to the circumference the number of degrees intercepted between the points where they cut the circumference is the measure of the angle between the two lines at the centre. Now 360 is four times 90, so that two lines containing a quarter of a circle make an angle of 90° between them. You will see that the size of the circle is of no consequence, for if you draw a number of circles, one inside the other, all having the same point for their centre, and from the centre draw two lines intercepting a quarter or 90° of the outer circle, then you will see that it intercepts also a quarter of each of the others. Each 90° is called a right angle, and two lines which make an angle or opening of 90° between them are said to be perpendicular to each other. A complete circle like this contains 360 angles of 1°, 4 angles of 90°, and so on.

127. Now astronomers conceive such a circle with its centre at the centre of the earth, and they can then by their observations determine the angles formed by the planes to which we have referred in Art. 125 ; and they have thus found that the angle made by the plane of the ecliptic, and the plane of the earth's motion of rotation is 23°, or thereabouts ; and the angle made by the plane of the ecliptic and the plane of the moon's motion round the earth, is a little over 5°.

§ IV.—WHAT THE MOON IS LIKE.

128. I have already referred to the teachings of Physical Geography with regard to the Earth. The moon is near enough to us, being only some quarter of a million of miles away, to enable us to learn much about its surface.

129. If the moon be looked at with the unaided eye its surface appears mottled, some portions being darker than others; and those darker places were thought by the ancients to be seas, and, although they have since been found to be dry land, they still retain the name of seas: so we have "Sea of serenity," "Sea of storms," and the like, as you will see on looking at a map of the Moon, for we have a map of the Moon as we have a map of the Earth. If you employ a telescope to aid the eye—and a small one will answer the purpose—the surface is seen to be almost completely covered with mountains, hills, and valleys, but not altogether mountains and valleys as we have them here, covered with verdure, but all dry and barren. There are no lakes or rivers, and, as far as is yet known, there is no water whatever, and consequently no clouds to shade the surface from the sun; and what is more, there is no appreciable atmosphere. Hence there is probably no life on the moon. Nearly the whole surface is covered with extinct volcanoes of enormous extent, and unlike those you read of on the earth.

130. You will see from these facts about the moon how the conditions of the planet on which we dwell may not apply to the other bodies in the skies. Fancy a world without water, and therefore without ice, cloud, rain, and snow, without rivers and streams, therefore without vegetation to support animal life: a world without twilight or any gradations between the fiercest sunshine and the blackest night; a world also without sound, for as sound is carried by the air the highest mountain on the airless moon might be riven by an earthquake inaudibly!

131. You will recognise, too, that the moon must resemble the earth in this: **it does not shine by its own light.** The bright part of the moon is that on which the sunlight falls; where this light does not fall the moon is invisible: hence moonlight is sunlight second-hand, and the moon does not give us light of its own.

132. The diameter (Art. 22) of the moon is about 2,000 miles; and, bulk for bulk, its materials are lighter than those of which the earth is built up, This is expressed by saying that the density of the moon is $\frac{2}{3}$, that of the earth being 1.

133. Now this requires a little explanation. You know that some things are very dense and heavy. others are very light; lead for instance is very dense and heavy, cork is very light. Now you know what an inch is, and a square inch, and a cubic inch. Suppose that you took a cubic inch of lead, and a cubic inch of cork, then, by weighing them both, you

would be able to tell exactly how much the lead was heavier than the cork. Calling the weight or density of the cork 1, the weight or density of the lead would be so and so. And of course if you took instead of a cubic inch, a cubic yard or a cubic mile, the lead would weigh exactly the same number of times more than the cork.

134. Astronomers have found out the weight of the earth, and of the moon, and they also know how many cubic miles (or cubic inches) each contains. They can therefore easily find whether a cubic inch or mile of the materials of which the moon is built up weighs less or more than a cubic inch or mile of the materials of which the earth is built up; in other words, whether the earth is less or more dense than the moon. And they have found that a cubic inch of the earth's materials weighs $1\frac{1}{2}$ times as much as a similar quantity of the moon's materials, hence they say that the moon is only $\frac{2}{3}$ as dense as the earth.

135. More commonly the weight or density of a cubic inch of water is taken as 1, then we say that the density of the earth is $5\frac{1}{2}$, and that of the moon $3\frac{1}{2}$ times greater than that of water. Thus then we have in the case of each celestial body:

a. **Its volume** expressed in cubic miles or cubic inches determined from its diameter.

b. **Its weight or mass**, that is to say how many tons it weighs; this is determined from its action on other bodies.

c. **Its density**, that is how much a cubic inch or cubic mile weighs ; this is found by dividing its mass or weight by its volume.

136. The same side of the moon is always turned towards us, for as the moon goes round the earth it slowly turns on its own axis, and makes one revolution in exactly the same time as it takes it to get round us, just in the same way as you would do if you were to take hold of a pole stuck in the ground, with your hands, and go round it, always keeping your face turned towards the pole. You would then see, by looking at adjacent objects, that you turned round once every time you went round the pole, and you will probably become giddy, thereby giving conclusive evidence of your rotation.

137. It follows from this fact that the moon only turns round once on its own axis during each revolution round the earth, and that the lunar days are about 29 of our days. We are lighted by the sun for about 12 hours, or the half of 24 hours ; each portion of the moon is lighted for about 14 days, or the half of 29 days, so you can imagine how intensely heated the surface must become during the lunar day, and how cold the opposite side must get during the 14 days' night.

III.—THE SOLAR SYSTEM.

§ I.—HOW BODIES LIKE THE EARTH, NEARER THE SUN, WOULD APPEAR TO US.

138. So far as we have gone the earth on which we dwell, the large sun and moon, and the tiny stars, are the only bodies with which we have dealt.

139. Let us see what we should observe in the heavens if there were other bodies, not shining by their own light—other earths like ours, revolving round the sun as we do. How would they appear to us? And first let us take the case of a body travelling round the sun but at a less distance from him than we are. Let us think. Take the lamp to represent the sun, the orange for the earth, and the ball used for the moon to represent the other earth; then all we have to do in order to represent the appearance of the new world in its journey round the sun, is to move the ball round the lamp, and see how it appears from the orange in its different positions. First place it in the position represented by *A*, Fig. 28, between the lamp and the orange—then it will appear in the same line with the sun, and accompany the sun in its path across the sky, at which time of course it will be invisible on account of the superior brightness of

the sun, but it will set and rise with it; now move it to *B*—it will then appear on the right side of the sun, and will rise before daylight and set before the sun, so that it would only be seen before sunrise, changing its place—"wandering" among the stars from day to day (the word planet means a "wanderer"), to be put out like the stars by the day. Move it to position *C*—it will then rise and set with the sun, and will be lost in the sun's rays as at *A*. Next move it to *D*—it is then on the left side of the sun and will rise after daylight, and set after sunset, so that it will be seen only in the evening. A little consideration will make it plain that this body will go through the same changes as the moon, and again that we can never see it at midnight. But there will be an important difference. As we go round the sun, keeping always about the same distance from the sun, the sun always seems to be about the same size; and as the moon goes round the earth, keeping about the same distance from it, the moon always seems to be about the same size.

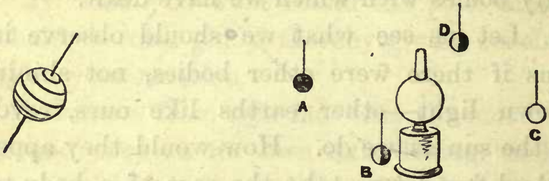


FIG. 28.—Diagram illustrating the motions and appearances of a body between us and the sun.

Mind, I do not say the same form. But the new earth about which we are now thinking goes round the sun; so it will sometimes be between us and the sun and sometimes on the opposite side of the sun, so that its distance from us will vary; therefore, its apparent size will vary.

140. Hence, if we were to examine this new earth with a telescope, we should see it vary in size and also in shape like the moon, and if its atmosphere were clear, we should see its seas and continents, and so by their motion we should be able to ascertain how fast it turned round on its axis—whether its day was longer or shorter than ours.

§ II.—HOW BODIES LIKE THE EARTH, FURTHER OFF FROM THE SUN, WOULD APPEAR TO US.

141. In order to represent the appearance of an earth outside us, we have only to move the ball in a circle round the sun, outside the earth's orbit. Let us begin by holding the ball on the opposite side of the sun to the earth—then it will be lost in the sun's rays, and on moving it further round in the contrary direction to the hands of a clock, it will be seen on the left side of the sun, and will therefore set after it just as the interior earth did; but as you move it on after it has made a quarter of a revolution, it appears to recede further and further from the sun, instead of

again approaching it, and passing between the earth and sun; and eventually it comes to the opposite side of the earth to the sun and rises at sunset, and is visible in the south at midnight, which as we have seen was impossible in the case of a body between the sun and the earth.

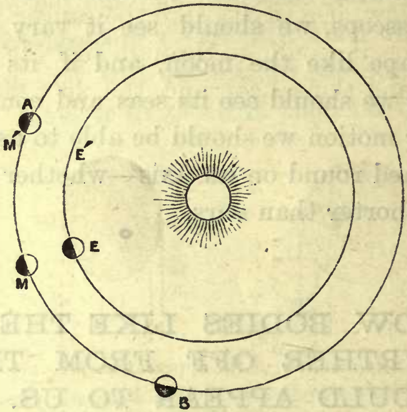
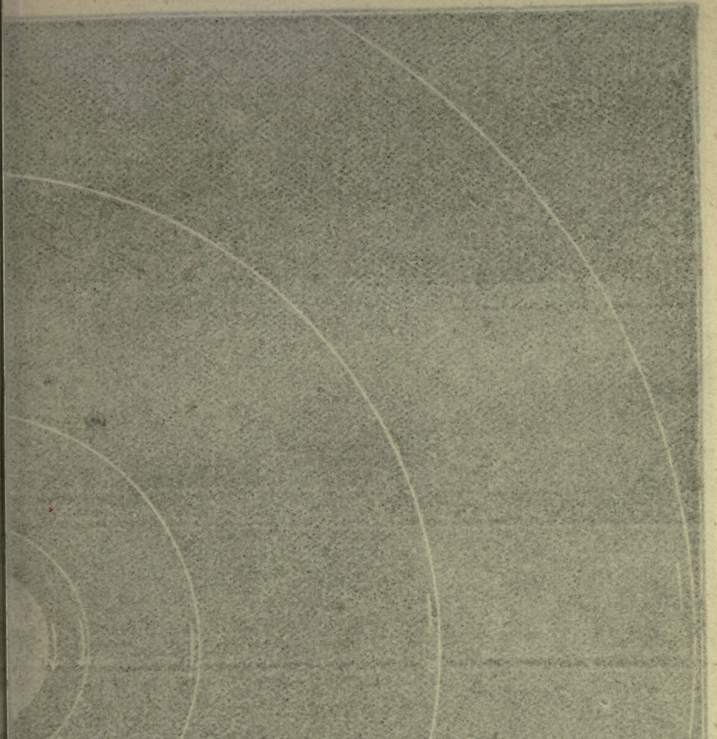
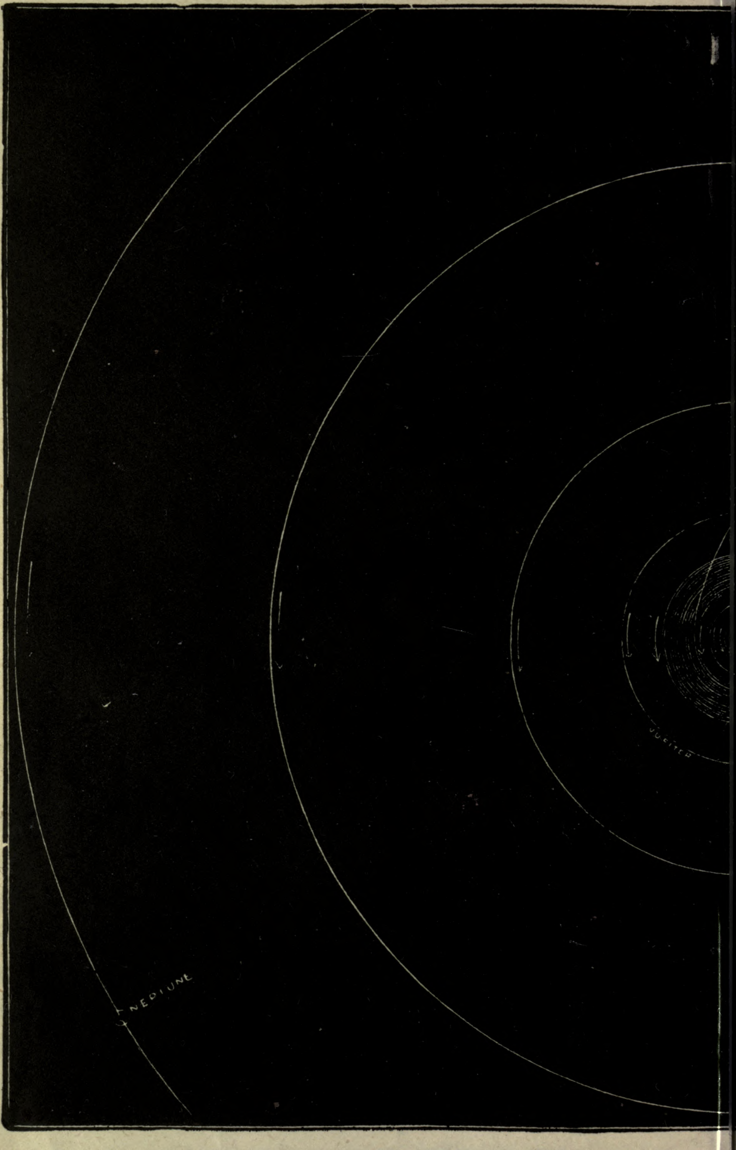


FIG. 29.—Diagram illustrating the motion of a body travelling round the sun outside the orbit of the earth.

142. You will also notice that nearly all the bright side is visible to the earth, although at the two positions corresponding to *A* and *B*, Fig. 29, it will show a portion of its dark side, so that an exterior earth would not go through all the changes that an interior one would do. While, therefore the interior earth would appear to swing from side to side of the sun, only the exterior one would take a sweep round outside our earth. Such a body will vary its size, but not to so great an extent as an interior one.

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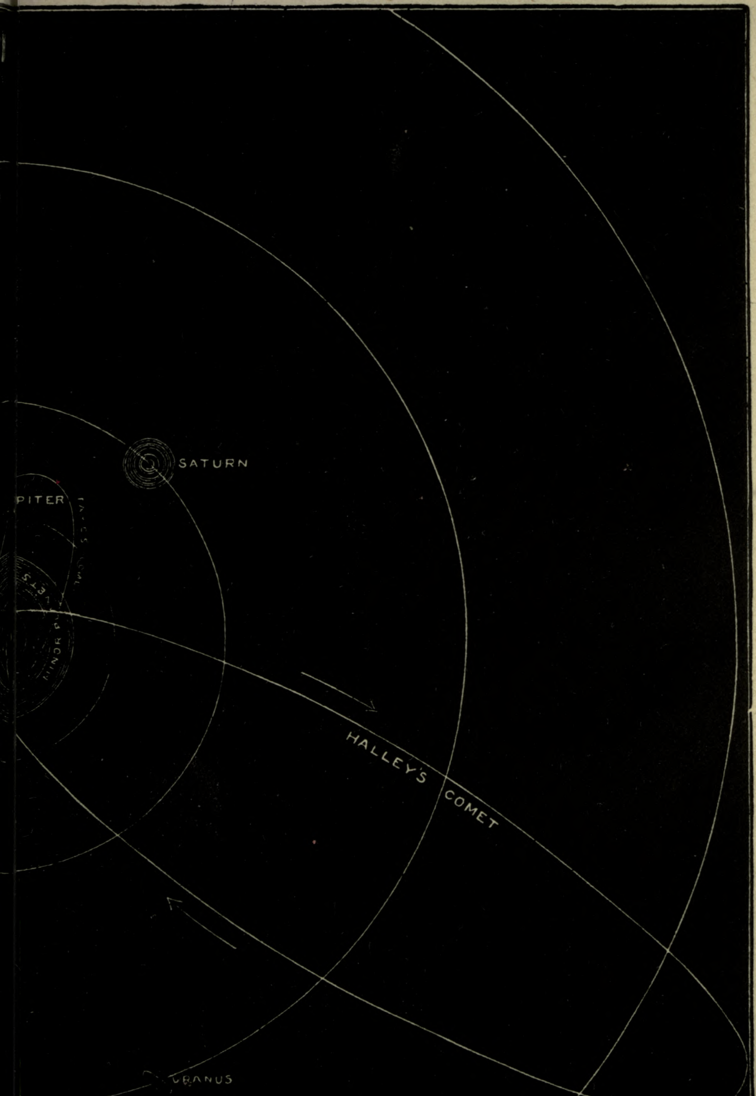
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§ III.—ARE THERE SUCH BODIES?—THE PLANETS.

143. There are such bodies as we have just been considering, both interior ones and exterior ones; and they are all called **Planets**, and the earth is called a planet simply because it, like them, would appear to wander among the stars to astronomers, if such there be, on the other planets. The principal planets are eight in number, including our Earth. They have been named after the ancient deities; the two interior ones, Mercury and Venus, and the exterior ones, Mars, Jupiter, Saturn, Uranus, and Neptune; the three first being smaller than our earth, and the remainder a great deal larger.

144. Mercury and Venus are known to be interior planets, that is, planets between us and the sun, because they appear to swing, as we have found such bodies should do, on either side of the sun. Mercury very seldom leaves the sun sufficiently to rise so early before the sun, or set so late after him, as to be visible. Venus, however, gets so far away as to be seen long after sunset or before sunrise, and is called the Evening or Morning star, accordingly.

145. The exterior planets, as we found such bodies should do, make a complete tour of the heavens. All these movements are, however, rather more complicated than we have found with the orange and ball,

for the earth is not fixed, but going round the quicker than the exterior, and slower than the int planets ; and, in order to represent the true appa motions, you must move the orange round the at a rate depending upon which planet you wish represent by the ball.

146. The sun and planets revolving round form what is called the **solar system** ; in f everything over which the sun has continued fluence is a member of this system.

147. Thus besides the planets there are oth members of the system, namely, comets and falli stars, which will be mentioned again more fully her after : all these bodies form a sort of family havin the sun for their head, and on Plate II. will be see a view of this system as it would appear whe looked at from above ; but it is impossible thu to give an idea of the true scale of the system. I order to do this, take a globe a little over two feet i diameter to represent the sun : Mercury would now be proportionately represented by a grain of mustard seed, revolving on a circle 164 feet in diameter ; Venus a pea, on a circle of 284 feet in diameter ; the Earth also a pea, on a circle of 430 feet ; Mars, a rather large pin's head, on a circle of 654 feet : the smaller planets by grains of sand, in orbits of from 1,000 to 1,200 feet ; Jupiter, a moderate sized orange, on a circle nearly half a mile across ; Saturn, a small orange, on a circle of four-fifths of a mile ; Uranus, a full-sized cherry, or small plum, upon the circum-

erence of a circle more than a mile and a half ; and Neptune, a good sized plum, in a circle about two niles and a half in diameter.

148. I have already told you that the earth's stance from the sun, represented in Art. 147 by half of 430 feet, is really about $92\frac{1}{2}$ millions of ies. I cannot give you any idea of this distance. can only state that if a train going at the rate of hirty miles an hour were to leave the earth on the rst of January, 1885, it would only reach the sun the middle of the year 2223.

149. Beginning with this rough idea we will now onsider the interior planets—those, namely, which re nearer the sun than the earth.

§ IV.—THE INTERIOR PLANETS.

MERCURY.

150. Mercury, the nearest planet to the sun, volves round him at a distance of about 40 millions miles ; the earth's distance from the sun being $92\frac{1}{2}$ illions, it has a diameter about one-third of that of e earth. It can be seen at certain times just after nset, and at others just before sunrise, as it never its the neighbourhood of the sun. It is eighty-four ys in traversing its orbit, so that its year is less en a quarter of ours. Its orbit is represented in ate II., and, like the moon's, is slightly inclined to

the plane of the ecliptic; that is to say, if the earth's orbit is supposed to be floating on the surface of water, part of Mercury's orbit would be slightly below the surface and part above. From the diagram you will see that Mercury will always appear to us near the sun. When it is on our left of the sun it apparently follows the sun on its daily course, and sets just after it; when on the other side it precedes the sun, and therefore sets before it, and so is only seen in the morning, when it rises just before the sun.

151. If Mercury be watched with a telescope it is found to go through the same changes as our moon, and for the same reason. You will understand this from Fig. 28, where the ball may be taken to represent Mercury in its different positions as it revolves in its orbit. When it is between us and the sun (or in what is called **inferior conjunction**) we do not see it, as its dark side is turned towards us, and as it moves round we see more and more of the bright side, till when it is opposite to us, or in what is called **superior conjunction**, we see the whole of the bright side.

152. Little is known of Mercury itself; we know not whether it has a land and water surface like the earth, or is waterless like the moon, whether it is enveloped in a dense cloudy atmosphere which protects the inhabitants, if such there be, from the intense heat of the sun, or not. We only know that its density (Art. 133) is greater than that of the earth.

VENUS.

153. Next to Mercury comes Venus, at about 67 millions of miles from the sun, with a diameter nearly as large as the earth. It can generally be seen either just after sunset or before sunrise, according to its

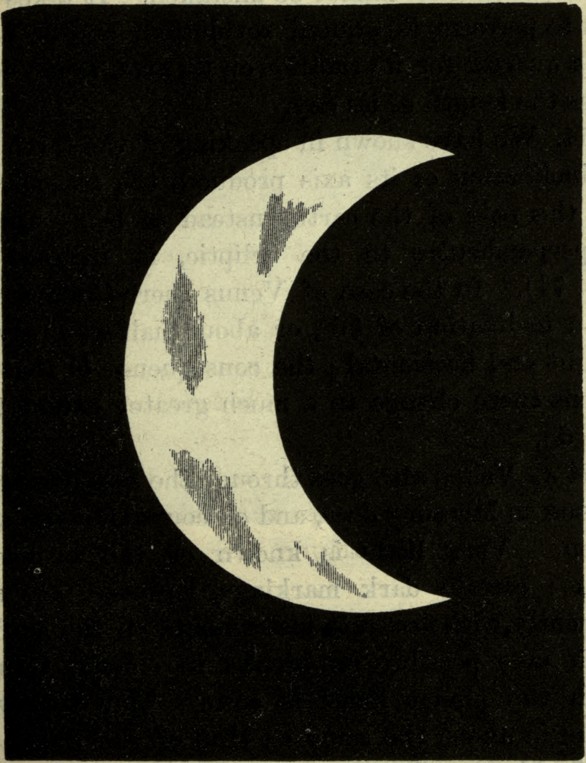

FIG. 30.—Venus, showing the markings on its surface.

position in its orbit round the sun, in the same manner as Mercury, only its orbit being outside that of Mercury it can get further away from the sun's apparent place among the stars, consequently we can examine it better. It is the brightest of the planets, and when visible cannot be mistaken. It takes 224 days to perform its annual revolution, and 23 hours and a quarter for its rotation on its axis, which determines the length of its day.

154. We have shown in speaking of the earth that the inclination of its axis produces the seasons, and that the pole of the earth, instead of being upright or perpendicular to the ecliptic, is inclined 23° (Art. 71). In the case of Venus there is affirmed to be an inclination of 50°, or about half-way between upright and horizontal; the consequence is that the seasons there change to a much greater extent than ours do.

154 A. Venus also goes through the same change of **phases** as Mercury does, and of course for the same reason. Very little is known of the surface of Venus: certain dark markings, however, are seen frequently with first-rate instruments on the surface, which may possibly be breaks in clouds, through which the planet itself is seen. The density of Venus is about the same as that of the Earth.

155. If you will think a little you will see that in the case of Venus the apparent size as seen from the earth should greatly change, as the nearer she is to us the larger would she be if we could see her

completely; so that, although like the moon she has phases, unlike the moon her size will alter. Let us inquire into this a little closer. When Venus is nearly between us and the sun—when, therefore, we can only see a fine crescent—she will be but some 25 millions of miles away from us (because we are about 92½ and she 67½ millions of miles from the sun); but

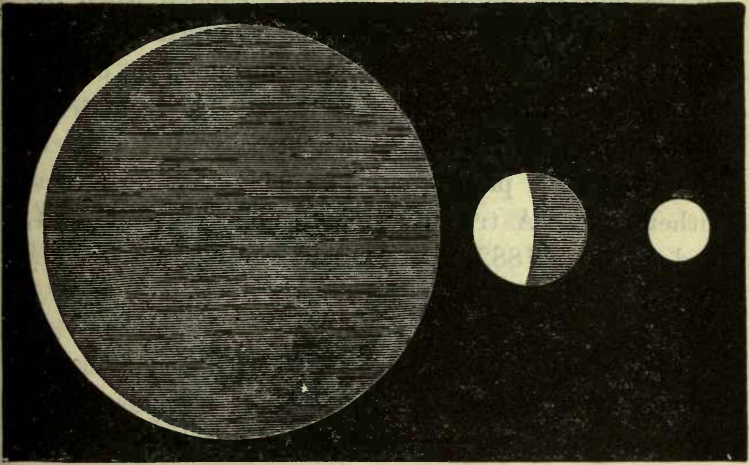

FIG. 31.—Apparent size of Venus at its least, mean, and greatest distance from the Earth

when she is on the other side of the sun she will be 160 millions away from us (that is, 92½ millions from us to the sun and 67½ millions from the sun to Venus on the other side), so that her size will vary in the proportion of 160 to 25, or say 6 to 1; hence the crescent of Venus will appear to form part of a circle 6 times larger than that presented by Venus when she is full to us. These changes are shown in Fig. 31.

156. Venus and Mercury, at times when they are on the earth's side of the sun, are visible as black spots on the sun's disc. This is called **a transit of Mercury** or **Venus**; that is, the passage of the planet exactly between us and the sun so that it is seen on the sun's disc.

157. A transit of an interior planet, like an eclipse of the sun by the moon, can only happen when the planet passes the sun at the time it is near one of its nodes, that is when it passes from one side of the plane of the ecliptic to the other. A transit, in other words, can only happen on the coincidence of the earth and planet and sun being in a line at either node. A transit of Venus happened in 1874, and again in 1882, it will not occur again for 105½ years.

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158. Next to Venus comes the Earth, the planet on which we dwell, and which has already been described. We therefore pass on to the exterior planets.

§ V.—THE EXTERIOR PLANETS.

159. The next member of our system is Mars. Mars revolves in an orbit having a mean or average distance of 141 millions of miles from the sun; its orbit is however so eccentric that when nearest the sun it is only 128 millions of miles, though at its furthest point it is 154 millions of miles, distant.

It revolves on its own axis in 24 hours and a half, making its days half an hour longer than ours. Its diameter is about one half that of our earth.

160. Mars requires 686 days to complete its annual revolution round the sun, making its year nearly double the length of ours. Since its orbit lies outside ours this planet never can pass between us and the sun, and consequently it does not show the same phases as Venus or Mercury; it however in two positions in its orbit becomes what is called **gibbous**, losing apparently its brightness to a small extent on one side, as will be seen in Fig. 29, where the two positions, when the earth is at *E*, are marked *A* and *B*, and at these two points a small part of the dark side will be turned towards us, presenting an appearance like the moon two or three days before or after full.

161. When Mars is on the opposite side of us to the sun at *M*, it is said to be in **opposition**; it is then at its nearest point to us (its distance being $128 - 92\frac{1}{2} = 35\frac{1}{2}$ millions of miles) and fully illuminated; so then this is the time to examine the planet. Its orbit is, however, very eccentric or oval, consequently it is much nearer the earth's orbit in one direction than in others; and when an opposition happens, when Mars and the Earth have their orbits closest together, we have a most favourable one, at which time Mars is only about half the distance it is from us at the most unfavourable one. The inclination of its axis is nearly the same as that of the

earth, being about 29°, so that the Martial seasons must be very similar to ours.

162. When looked at with the eye alone, Mars appears of a reddish tint, by which it can be easily recognised, but when seen through a telescope the redness in a measure disappears, and the planet appears to have a bright surface, on which are darker portions, the former being the lands, and the latter the seas. Mars is the most remarkable among the planets in this, that it appears to us as the Earth would appear to the inhabitants of Mars. Around the poles the surface appears white, and on watching the

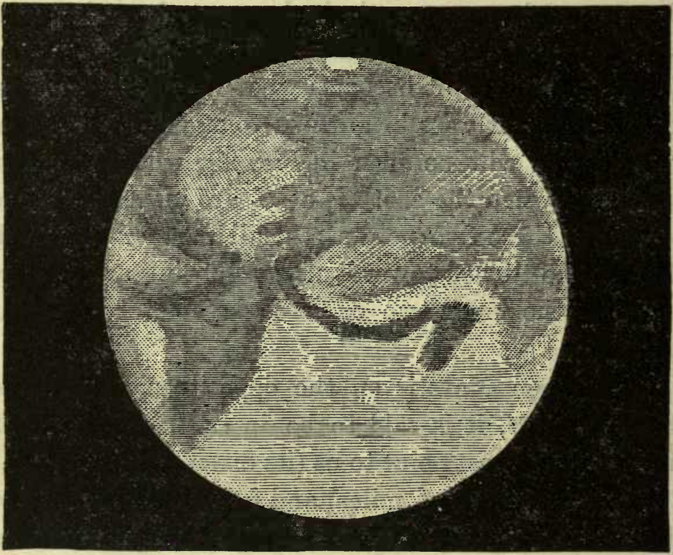

FIG. 32.—Mars, showing snow cap at the pole, and the lands and seas.

spots from time to time each is seen to grow small as summer is approached in that hemisphere, while the opposite one gets larger in winter, so we suppose these to be the polar snows corresponding to those on our earth. The drawings will give some idea of the appearance of Mars as seen in a large telescope, one

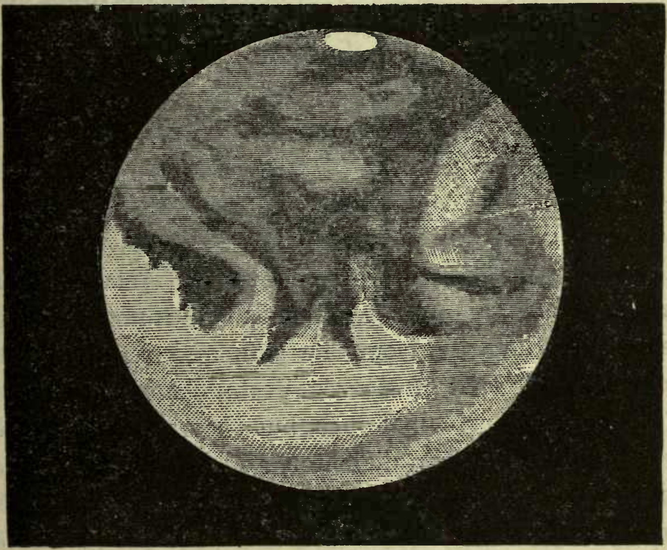

FIG. 33.—Mars. View of another part of the planet.

of the main features being, that instead of there being about four times more water than land as on our earth there is on Mars about four times more land that water.

MARS' SATELLITES.

162A. Till quite recently it was supposed that Mars had no moons; but in 1877 two were discovered close to the planet, the outer one making a revolution round Mars in 30 hours 18 minutes, and the inner one in 7 hours 38 minutes. These two moons may be put down as by far the smallest heavenly bodies yet known.

THE ASTEROIDS.

163. Beyond Mars we come to the Asteroids, or minor planets, a number of small bodies not varying greatly in distance from the sun, and revolving in orbits outside that of Mars. Vesta, Juno, Ceres, and Pallas are the principal ones, but they are only some few hundred miles in diameter, and are barely visible to the naked eye, if at all, and from their smallness are worth little notice. Their orbits are more inclined to the plane of the ecliptic than those of the larger planets, but we have no knowledge of the inclination of the poles of these small planets to their orbits. Their number is large, about 200; and we say about, for several are discovered every year, and the names of nearly all the deities must have been used for them. The greater number of them are only equal to a 10th magnitude star in brilliancy.

JUPITER.

164. Outside the orbits of the numerous asteroids is the largest planet of our system, Jupiter, a body that has no doubt been pointed out to you some time or other. When above the horizon, it is unmistakable by its excessive brightness, being only surpassed by Venus, which can generally be distinguished from it by its proximity to the sun. Jupiter revolves in an orbit at a mean distance of 480 millions of miles from the sun, completing his year in 4,333 days.

165. When observed with a telescope of moderate power, Jupiter appears of an oval shape, very much flattened at the poles, and crossed by several dark belts, as represented in the figure; large black spots and other markings of which we shall say more presently, are also frequently seen on the surface, and from the motion of those markings, the time of rotation on its axis has been ascertained to be about 10 hours, that is less than half one of our days, and its diameter is found to be about ten times the diameter of our earth, so that the flattening of the poles and the protuberance of the equator must necessarily greatly exceed that of our earth, for the velocity that the equator moves at must be twenty times the velocity of our planet at the equator, or 20,000 miles per hour.

166. We have mentioned the belts and other markings on its surface; it is probable that Jupiter is

covered with clouds, giving rise to its bright appearance, and that the dark belts are openings in the clouds through which we see the darker surface of the planet, or more probably of lower beds of clouds beneath.

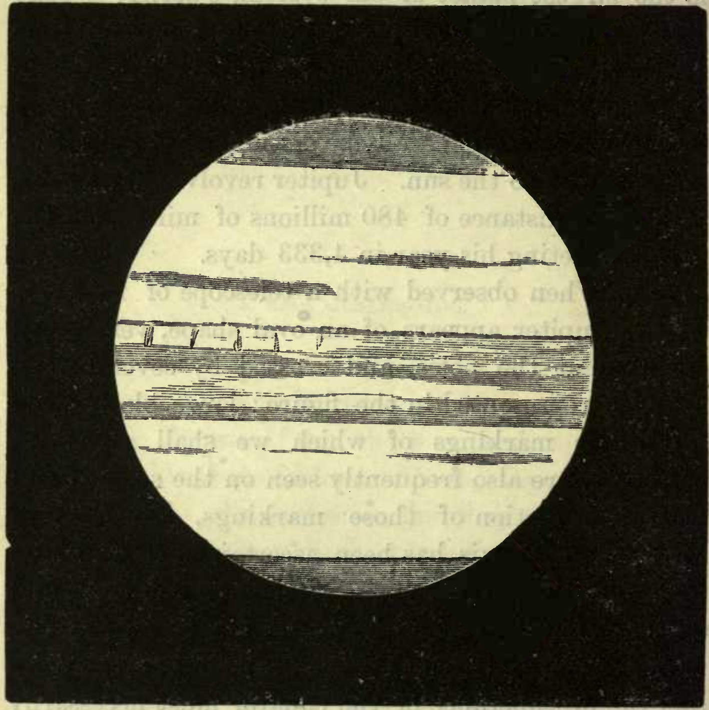

FIG. 34.—Jupiter, showing the cloud belts.

The number and size of the belts are continually changing, and bridges of cloud are constantly being thrown over the dark spaces, clearly showing that it is not the surface of the planet we see, but only a very cloudy atmosphere.

167. Jupiter has four satellites or moons revolving round him, and going through the same changes as our own. They are all nearly of the same size, about 2,200 miles in diameter, but at different distances, and consequently they take very different times to revolve round their primary, Jupiter; the first taking less than 2 days, the second 3½ days, the third 7 days 3 hours, the fourth 16¾ days. They all revolve in orbits very slightly inclined to the plane of Jupiter's orbit, and consequently whenever they pass between the sun and Jupiter there is an eclipse of the sun visible on some part or other of the planet's surface; only the fourth has an orbit sufficiently inclined to enable it to pass above or below the line joining the sun and Jupiter, this prevents it from causing an eclipse at every revolution. For the same reason of

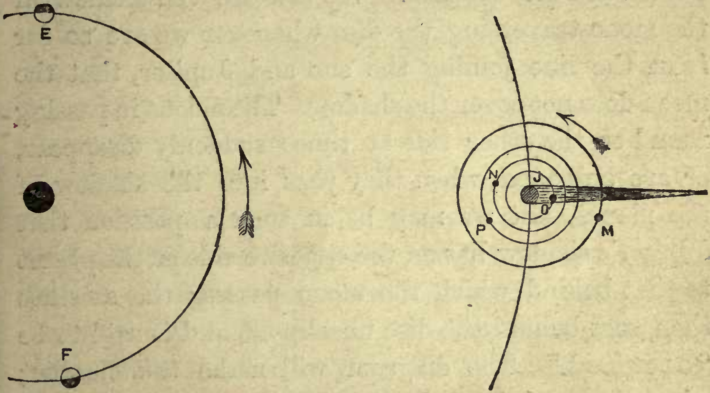

FIG. 35.—Diagram explaining the eclipses, occultations, and transits of Jupiter's satellites.

course the moons also are eclipsed at every revolution when they pass through the planet's shadow.

168. When viewed with a telescope the moons appear to oscillate on either side of Jupiter (just as the interior planets appear to us to oscillate on either side of the sun), and in their passage from one side to the other they generally pass over the disc of the planet; there is then what is called a "**transit**" of the moon over the disc. We also see the shadow of the moon traversing the disc whenever we are so far from the line joining the sun and Jupiter, that the moon does not cover the shadow. The moons in passing round on the other side at times suddenly disappear, or are **eclipsed**, when they pass into the shadow of the planet, but we may be in such a position that Jupiter's shadow lies on the opposite side of the planet to that behind which the moon passes; the satellite then goes behind the disc uneclipsed, and is said to be "**occulted.**" The diagram will make this clearer; when the earth is at the point *E* of its orbit, the moon *N* appears in transit, while the *M* is occulted and *O* eclipsed, and from this point of view every satellite must be occulted before it is eclipsed; but when the earth is at *F* the moon *M* is no longer occulted, and will pass into the shadow and become eclipsed without an occultation, and from this point *P* will be in transit and *O* also eclipsed, but as soon as it leaves the shadow it will be behind the planet, and will reappear from an occultation.

169. The inclination of Jupiter's axis is very small,

only a little over 4°, so that there can be no appreciable change in the Jovian seasons. Although the size or, more correctly speaking, the volume, of Jupiter is more than 1,300 times that of the earth—that is, 1,300 globes of the size of our earth, if made into one world, would only be of the size of Jupiter—still its weight is only 300 times the weight of the earth, so that the materials composing Jupiter are of a much lighter kind than those composing the earth; thus representing the density of the earth by 1, Jupiter's density is less than $\frac{1}{4}$.

SATURN.

170. We next come to Saturn, a truly grand sight in a telescope, Saturn having, besides eight moons, an immense bright ring surrounding the globe. This planet revolves in an orbit at about 880 millions of miles from the sun, taking 10,759 days, or nearly thirty of our years, to complete its year, and having a diameter nine times greater than that of the earth. From observations of spots and belts on the surface (somewhat similar to those on Jupiter) the time of its diurnal revolution has been fixed at about $10\frac{1}{2}$ hours, a little longer than that of Jupiter, and it is probable that Saturn has much the same constitution as that planet, as it appears to us to be covered with an extensive cloudy atmosphere producing belts as on Jupiter; it is also made up of very much lighter materials than our earth is, materials of only half the

density of those composing Jupiter. Saturn's axis is inclined at an angle of about 26½°, so there are seasons there as on our earth.

171. Now as to the rings, what are they? Their general appearance is that of three rings lying outside each other in succession as shown in the diagram, Fig. 36, the diameter of the outer ring being about

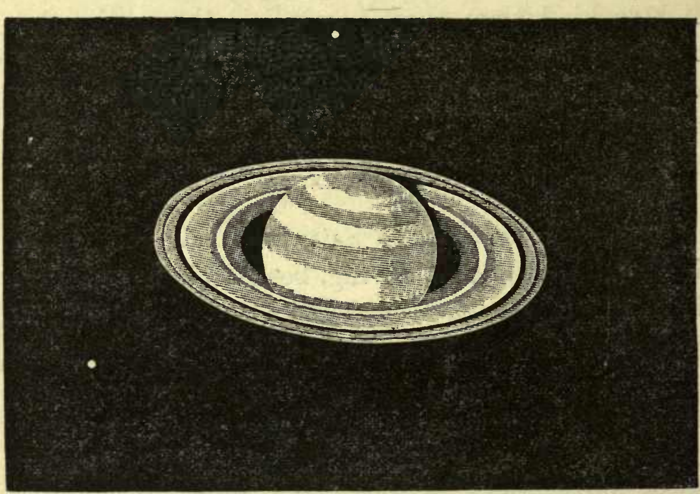

FIG. 36.—Saturn and his rings.

166,000 miles. The two outer ones are the brightest, the inner or crape ring being only just visible in a large telescope, the ball of the planet being seen through it. In spite of their enormous breadth, the thickness of the rings is only about 138 miles, and when edgeways to us, as is the case in certain positions, as Saturn moves in its orbit, they are barely visible in the best telescopes. It is thought that the rings represent a vast assemblage of small satellites or moons revolving round Saturn.

172. The moons of Saturn, eight in number, are not of such interest as those of Jupiter. Their distance from us precludes us generally from observing their eclipses and occultations; their orbits also are largely inclined to the orbit of Saturn, and consequently eclipses are rare.

URANUS.

173. We next come to Uranus, of which little is known, its distance—1,770 millions of miles from the sun—being so immense; it takes 30,686 of our days to complete its annual revolution, and it is known to have four moons. Its diameter is four times greater than that of our earth, and its density is about $\frac{1}{5}$ that of the earth.

NEPTUNE.

174. Then comes Neptune, the most distant planet of our system at present known; the distance of Neptune from the sun is not far from double the distance of Uranus, and it takes 60,126 days to go round the sun. Its diameter is over four times greater than that of our earth, and its density is slightly less than that of Uranus.

175. Its discovery is interesting as showing how the position, mass, and other attributes of a planet can

be calculated by their effect on other bodies at a distance before the planet has actually been seen. It had been noticed for a long time that Uranus moved at one part of its orbit more slowly, and at another, faster, than its proper rate, and from these observations the position, mass, period, &c. of the planet were determined before it had ever been seen, and it was found very close indeed to its calculated place. Neptune has only one moon at present discovered.

§ VI.—COMETS, METEORITES, AND FALLING STARS.

176. Besides the planets, there are other members of our system, of a different kind. We may say that the planets are the members of the solar household, the bodies we are about to consider are visitors.

177. Those who have seen a comet will not require to be reminded of the strange appearance of those bodies, and those who have not seen one will get some idea of what this class of bodies is like from the diagram. Comets vary so much in form and size and brightness, that no two are precisely alike : sometimes they resemble a small planet or star with a bright point called the **nucleus**, an immense tail stretching for millions of miles behind ; at other times they appear with a nucleus with mist extending equally round it ; in fact, their shapes are almost as various

as those of the clouds. The greater number of comets are invisible to the naked eye.

178. The majority of comets that come into our system from outside are attracted towards the sun, pass by it, and then continue on away from our system again; while there are others that belong to our system, and revolve round the sun as the planets do, only instead of having nearly circular orbits, their paths are very eccentric, so that the comets approach near the sun at one time, and then recede to immense distances away. There are several such comets whose orbits are known, and these are called after their

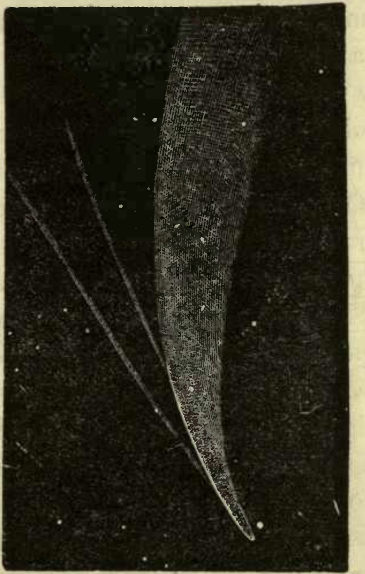

FIG. 37.—General view of a Comet.

discoverers; such as Encke's comet, which revolves round the sun once every five years, and Halley's, that has a period of about seventy-four years.

179. The orbits of comets have very various, and some of them very great, inclinations, not like the orbits of planets, which all lie nearly in the same plane, the plane of the ecliptic; the majority go round the sun the contrary way to planets, and are said to have a **retrograde** motion.

180. Their weight is excessively small, while their volume or bulk is immense—that of Donati, figured in the diagram, having a tail millions of miles long, through which faint stars, which a thin cloud or puff of smoke would obscure, were visible. As a comet approaches the sun, **envelopes** or **jets** are formed.

181. Now, before I say anything more about these strange things, I must remind you that perhaps when you have been looking at the sky, you may have noticed a bright point, like a star, shoot rapidly across the heavens, leaving a bright streak for a second or two behind it. Several may generally be seen every fine night with a little attention. These are called **meteors** or **falling stars**, or, if they actually fall, as some do, to the earth, **meteorites**. They vary greatly in apparent size and brightness, the smaller being most prevalent; the larger, called meteors, are rare, and sometimes appear as large and almost as bright as Jupiter or the Moon, and traverse the sky for some seconds, leaving a luminous trail behind them.

182. Now of course, as some of these bodies fall to the earth, the chemist can examine them and find out what they are made of, as he has found out what the earth is made of. Some are especially metallic in their nature, others especially stony. As they rush into our atmosphere they become so hot that they burn, and the small ones are consumed before they can reach the earth; the larger, on the other hand, are not entirely consumed, though melted on the surface and considerably reduced in size. A number of these that have escaped destruction are to be seen in the

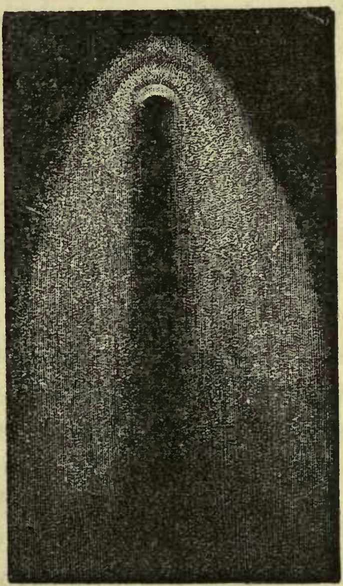

FIG. 38.—Head and envelopes of a Comet.

British Museum, some reaching the weight of three tons.

183. From constant observation it has been found that on different nights the majority of shooting stars appear to come from certain parts of the sky, and on certain nights in the year many more fall than on others. There are, for instance, the well-known falls of November 13 and August 10, those of November coming from the constellation Leo, and consequently called the Leonides, and those of August from Perseus and called the Perseids.

184. We now know that these meteors travel round the sun as the planets do, and the strange thing is that when we come to examine the shape, size, and position of their orbits, they are found to be the same as those of some of the comets; so that since some meteorites and comets have the same path or orbit, it has been suggested that comets are clouds of meteorites. This hint of a connection between comets and meteorites is one of the greatest discoveries of late years in the science of astronomy; and the observations on the beautiful comet visible in 1874 have shown that possibly the heat and light of a comet may be due to the clashing together in space of these very bodies which, when they fall into our air, give rise to the appearance of falling stars, for we know that comets are not very hot, that they do partly consist of solid particles or masses, and that the vapour given off is that of a substance known to exist in meteorites.

185. Comets, from their sudden and curious appear-

ance, were looked on with great awe by the ancients, and all kinds of calamities were attributed to them. We learn, for instance, that about the year 975 the Ethiopians and Egyptians felt the dire effects of the comet to which Typhon, who reigned then, gave his name. It appeared all on fire, and was twisted in the form of a spiral, and had a hideous aspect. It was not so much a star as a knot of fire. We thus see how science replaces the terror felt in past ages by an admiration of the wonders of the universe in which we dwell.

IV.—THE SUN—THE NEAREST STAR.

§ I.—THE INFLUENCE OF THE SUN IN THE SOLAR SYSTEM.

186. In what has gone before I have tried to show you what the earth is—(I do not mean what it is made of; that you will learn in the Chemistry Primer: or what it is like—how its surface is one of land and sea, or how it is surrounded by an atmosphere—that you will learn in the Physical Geography Primer)—and we have found that it is a cool body travelling round the sun, and because it is cool it has no light of its own, its light being, as a matter of fact, borrowed from the sun.

187. Next, I have shown you that it is one of several

similar bodies travelling round the sun, which bodies, called planets, are cool like the earth, and as such they give out no light of their own.

188. We have also seen that the length of the earth's year, and of the years of the other planets, depends upon the time each planet takes to go round the sun ; and further, that the length of the earth's day, and of the days of the other planets, depends upon the rate at which each planet spins round, and so brings each part of its surface into the sunlight.

189. Further, we have seen how the inclination of the axis of the earth, and of that of each planet, determines the seasons, the change of which is chiefly due to the difference, at any one period of the year, between the time during which each part of a planet is exposed to the sun and the time during which it is withdrawn from the sun's influence.

190. So that you see the sun has to do with everything. What, then, is this Sun, which occupies the central position round which all the planets travel, and which is so important to them that their very life as it were depends upon its rays?

§ II.—THE HEAT, LIGHT, SIZE AND DISTANCE OF THE SUN.

191. First, I have to tell you that you may regard the sun as a globe of the fiercest fire : the heat of the sun is so enormous that it is useless for me to attempt to

give you any idea of it. Remember, I have already told you that the other planets, like the earth, are cool bodies; that is, bodies on the surface of which various substances can exist in the solid state: hence we talk of the "solid earth." But on the sun nothing is solid, everything exists in the shape of white-hot vapour.

192. Next, I have to tell you that in consequence of this tremendous heat, the sun shines by its own light. Remember, I have told you that the planets and their moons (including of course our moon) do not.

193. And lastly, I have to tell you that the sun is a globe of such enormous dimensions, that it is 500 times larger than all the planets put together. If you were to take nearly 1½ millions of Earths, and knead them into a ball, you would then have a globe about as large as the sun.

194. I have already told you that the distance of the sun from us is about 92½ millions of miles. To go into the mode of measurement would lead us too far into mathematics for my present purpose; but it may be stated here that knowing its distance and apparent size, we can proceed to find its diameter in this way. Let us draw imaginary lines from either side of the sun to the eye, as AB and AC, Fig. 39, CB representing the diameter of the sun, we find that the inclination of the two lines to each other is such that all lines drawn from one line to the other, as DE or FG, are equal in length to $\frac{1}{107}$ of their

distance from *A*, so also *B C* is $\frac{1}{107}$ part of the distance from *A B*, which we know is 92½ millions of miles; dividing this by 107 we get 850,467, which is the distance from *B* to *C*, or the diameter of the sun in miles.

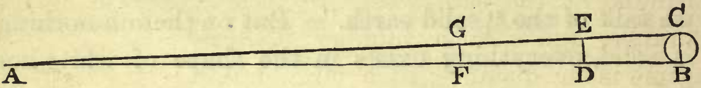

FIG. 39.—How the size of the sun is determined.

§ III.—WHAT THE SUN IS LIKE.

195. There are not many observations that can be made on the sun without the aid of a telescope and dark glasses, and its intense heat and light render it dangerous to look at it without special precautions.[1] If you smoke a piece of glass over a candle, and look at the sun through it, it will appear to be a round bright object, because each part of it shines by its own light: unlike the moon, it is always round. This bright part is called the **photosphere**. In telescopes black **spots** are frequently seen on its surface, and these, indeed, are sometimes of sufficient size to be visible without the telescope.

196. In the neighbourhood of the spots brighter portions than the general surface are seen: these

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[1] The young reader must not attempt to look at the sun through a small telescope, for he or she may be blinded in the attempt.

are called **faculæ**, and probably are immense banks of brighter vapours several thousands of miles long. If the spots and faculæ be watched from time to time they will be found to be constantly changing their shape.

§ IV.—SUN-SPOTS.

197. Although the sun is so far away from us, in consequence of its immense size and the violence of the forces at work, these spots are fine objects in the telescope. I give a drawing of one (Fig. 40) so large that several Earths might have been hurled into it.

198. If these spots be observed and their positions carefully noted, and again observed one or two days afterwards, they will be found to have changed their position towards the west, and they will be seen to be gradually moving from the east side of the sun's disc to the west, where they will gradually disappear.

199. Now, since all of these have the same motion in the same direction, it is evident that the surface of the sun is moving and carrying the spots with it, and if a well-marked spot be observed when passing off the disc to the west, it may be found about 12 days after to appear again on the east side and get to the position where it was first observed in about 25 days, having in that time gone right across the disc and round the back.

200. The surface of the sun has therefore moved round in 25 days, or in reality the whole sun itself is turning round on its axis at this rate, carrying spots and faculæ with it.

201. Let us now see what kind of thing a spot is. If a pretty regular one is observed near the middle of the disc it appears round; if it be again observed a few days after, near the edge, it will appear no longer of the same shape, the darkest middle part having apparently moved to the left while the half shade round it has vanished. Let us see what we can learn from this. Take an ordinary saucer, and having blackened the part of it on which the cup generally stands, look

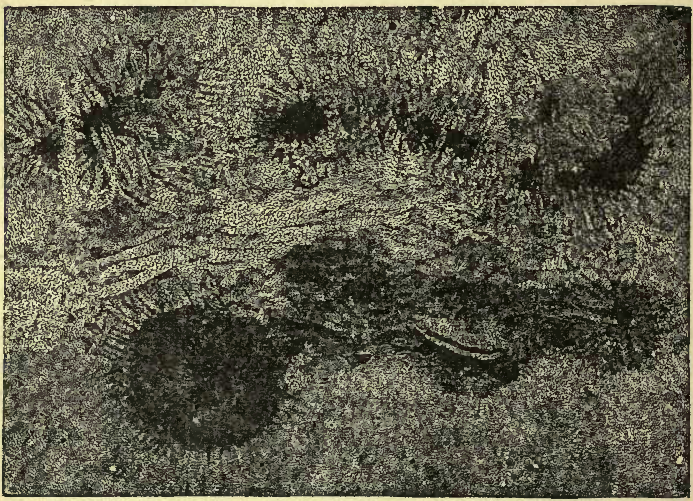

FIG. 40.—A Sun-spot.

straight at it—you will see the black part equally surrounded by the sloping sides, as at *A*; now twist the saucer till it is seen more edgewise, and you will see the edge on the left hand quite disappear, while the right side is nearly flat in front of the eye, and it will have the appearance of *C*.

202. Now, if a cavity like the saucer were cut on a large globe, it would go through just the same changes that we find the saucer and the spot do, so we may conclude that the spots on the sun are hollows in the bright substance of the sun; but it is found from other evidence that these hollows are not empty, but filled with gases stopping the light given out below.

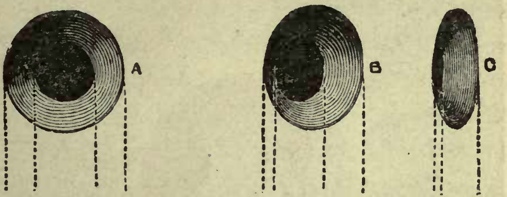

FIG. 41.—Explanation of the appearances presented by Sun-spots.

§ V.—THE SUN'S ATMOSPHERE.

203. The round sun that we see is not all there is of the sun, but only the denser part of it; the less dense and luminous vapours extend for hundreds of thousands of miles beyond the visible sun; but

generally we cannot see them any more than we can the stars; still, in Eclipses, when, as we have seen, the light of the sun is cut off by the moon, we can see them, as we can see the stars (Art. 114). The luminous vapours then appear of exquisite colours, red being most common. These vapours, however, get brighter near the sun, and form an envelope round him, called the Chromosphere, and these can be observed by a special method. It is then seen that the lighter vapours of the real sun are shot up into its outer atmosphere, called the **coronal atmosphere**, taking fantastic shapes called prominences, and these prominences rapidly change.

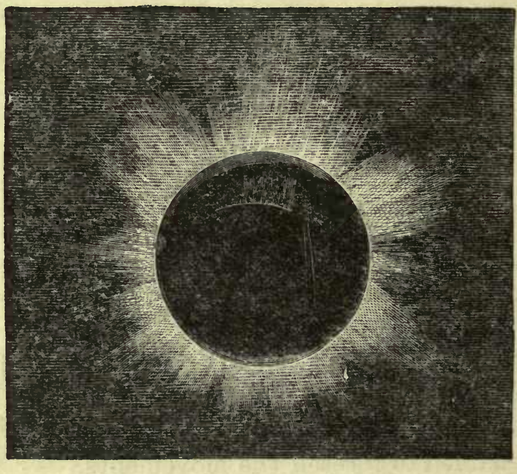

FIG. 42.—The Sun's coronal atmosphere.

§ VI.—WHAT THE SUN IS MADE OF.

204. By analysing the light of the sun by means of a spectroscope, an instrument that splits light up into its component colours, in the same manner as you have seen light split up into all the colours of the rainbow by the glass drops on chandeliers, it has been found that a great number of our metals exist in the sun, not of course in their metallic state, but in a state of vapour, the heat there being so intense that the metals evaporate as water with us does into steam. There are first of all, among the elements that we know here, the gas hydrogen, and then vapours of magnesium, calcium, sodium, iron, manganese, nickel, barium, strontium, and very many more metals, besides probably other gases, not yet found on the earth.

205. Since, as we have seen, the sun is so largely composed of gases, you will not be surprised that its density is much less than that of the earth; indeed, it is less than a quarter of that of our planet.

§ VII.—THE SUN IS THE NEAREST STAR.

206. I have been careful to dwell at some length on what is called the physical constitution of the sun, not merely because in it we have an example of

a class of bodies very unlike the planets, as we have seen, but because we now know that **the sun is a star**; bigger and brighter than the other stars, not because it is unlike them, or even larger, but simply because it is so near to us.

207. We can now, then, define the solar system to consist in the main of a number of cool bodies revolving round a hot one. **As we can take the earth as a type of the planets, so we can take the sun as a type of the twinkling stars that people the depths of space**; and it is not too much to believe that every star is surrounded by its family of planets in the same way as the sun is.

V.—THE STARS.

§ I.—THE STARS ARE DISTANT SUNS.

208. From the sun—the nearest star—that gives us heat and light, we must now turn to the more distant ones. After what has been stated you will not be surprised at my turning from a large body like the sun, the beams of which are so hot, to those tiny specks of light distributed in the heavens, the heating power of which is imperceptible, since those little twinkling bodies are suns, giving out light and heat like our sun, only they are at such incredible distances from us,—the distance of some of the nearest stars is more than

500,000 times the distance of our sun,—that their size becomes inappreciable : we have, nevertheless, reason for believing that many of them are several hundred times larger than our sun.

§ II.—THE BRIGHTNESS OF THE STARS.

209. When we look at the stars at night, one of the first things we notice is that they are of different brightnesses. Is it that some are smaller than others, or are the brightest the nearest to us? It is difficult to say exactly, for in some cases the bright stars are nearest to us, and in others there are small ones as near, so that both size and distance come into play.

210. Stars are classed in **magnitudes** according to their order of brightness, the brightest being said to be of **the first magnitude**, the next of the second magnitude, down to the fifteenth and sixteenth, which require the most powerful telescope to view them. The faintest star visible on a dark night is of about the sixth magnitude. After what has been said you must not think that magnitude means real size, as a large star may be far away, and so be classed so far as brightness goes with a smaller one nearer to us.

211. There are about 3,000 stars from the first to the sixth magnitude visible at once to the naked eye, and there are over 20,000,000 visible in large telescopes.

212. You may have also noticed, on a clear dark

night, a zone, or band of faint light, stretching from the horizon on one side, nearly over our heads to the horizon on the other. This is called the **milky way.** It is composed of an almost infinite number of small stars, apparently so close together as to form a luminous mass; and of the 20,000,000 telescopic stars, probably 18,000,000 are in the milky way. A view of this gives us some little idea of the immensity of our universe, if we consider that it is not the real closeness of the stars that we observe, but only their apparent closeness, placed, as they probably are, one almost behind the other so as to be in nearly the same line of sight, and at a distance from each other perhaps as great as that from our sun to the nearest star.

213. If you suppose a wood in which all the trees are the same distance apart, and you place yourself in the wood near one side of it, the trees will appear nearest together on the other. So is it with the stars in the Milky Way; there is the greatest number of stars in the line of sight.

214. The colours of the stars are various, some being white, others orange, red, green, and blue. For instance, Sirius is white, Arcturus yellow, Betelgeuse red, but these colours are more noticeable with a telescope than with the eye alone.

§ III.—THE CONSTELLATIONS.

215. The stars have been grouped, as long as history carries us back, into **constellations**, each one of which received some fanciful name according to the being or object the stars composing it were thought to represent. The sun in his course passes over the **zodiacal constellations**, visible of course both in the Northern and Southern Hemispheres of the Earth. These are Aries, Taurus, Gemini, Cancer, Leo, Virgo, Sagittarius, Capricornus, Aquarius, and Pisces, the Latin names for the Constellations, the order of which you will remember from the following rhyme :—

> "The Ram, the Bull, the Heavenly Twins,
> And next the Crab, the Lion shines,
> The Virgin and the Scales,
> The Scorpion, Archer, and the Goat,
> The Man that holds the watering-pot,
> And Fish with glittering tails."

216. The constellations visible in the Northern Hemisphere above the zodiacal constellations, are called the **northern constellations**, they are as follows :

Ursa Major.	The Great Bear (The Plough).
Ursa Minor.	The Little Bear.
Draco.	The Dragon.
Cepheus.	Cepheus.
Boötes.	Boötes.

Corona Borealis.	The Northern Crown.
Hercules.	Hercules.
Lyra.	The Lyre.
Cynus.	The Swan.
Cassiopeia.	Cassiopeia (The Lady's Chair).
Perseus.	Perseus.
Auriga.	The Waggoner.
Serpentarius.	The Serpent-Bearer.
Serpens.	The Serpent.
Sagitta.	The Arrow.
Aquila.	The Eagle.
Delphinus.	The Dolphin.
Equuleus.	The Little Horse.
Pegasus.	The Winged Horse.
Andromeda.	Andromeda.
Triangulum.	The Triangle.
Camelopardalis.	The Camelopard.
Canes Venatici.	The Hunting Dogs.
Vulpecula et Anser.	The Fox and the Goose
Cor Caroli.	Charles's Heart.

217. The constellations visible in the Southern Hemisphere above the zodiacal ones, called the **southern constellations**, are:

Cetus.	The Whale.
Orion.	Orion.
Eridanus.	The River Eridanus.
Lepus.	The Hare.
Canis Major.	The Great Dog.
Canis Minor.	The Little Dog.
Argo Navis.	The Ship Argo.
Hydra.	The Snake.
Crater.	The Cup.
Corvus.	The Crow.
Centaurus.	The Centaur.

Lupus.	The Wolf.
Ara.	The Altar.
Corona Australis.	The Southern Crown.
Piscis Australis.	The Southern Fish.
Monoceros.	The Unicorn.
Columba Noachi.	Noah's Dove.
Crux Australis.	The Southern Cross.

218. In order to learn the positions of the various constellations and stars you will want a star-map or planisphere, and will also require some friend to point out to you some of the chief constellations to begin with. I have indicated a few of these by Roman letters in the preceding lists.

219. The stars in each constellation are known by the prefix of some letter of the Greek alphabet, the brightest being called Alpha (α), the second brightest Beta (β), and then, when all the letters are used, they are numbered 1, 2, 3; so we can refer to a star as Alpha (α) Lyræ, the brightest star in the constellation of the Lyre, or (β) Cygni, the second brightest in the Swan, 61 Cygni, and so on, so that every star can be named. In addition to these names the principal stars have other names, thus α Lyræ is also called Vega, α Canis Majoris is called Sirius, α Boötis, Arcturus, and so on.

§ IV.—APPARENT MOVEMENTS OF THE STARS.

220. We saw in speaking of the earth that it was only a moving observatory, and that therefore we must distinguish the real motion of external bodies from that of the body on which we dwell. We may now return to this subject. Let us compare the earth to a boat at sea; imagine yourself in the boat; then if it be suddenly turned round, all the ships in sight will, if you are ignorant of your motion, appear to go round you in the opposite direction; but it would be highly improbable that all the ships in sight should do so at the same rate, keeping their relative positions to each other, so that you would at once find out that your boat was moving, and not the ships. Just so, as we have seen the earth turns round, and not the stars round us, so the daily motion of the stars is only apparent.

221. Now, let the boat be rowed round a ship. The relative positions of the ship and the distant craft change, the ship appears to move round you, passing between you and the other ships in succession. The same appearance would be produced were the boat to remain still, and the distant ships to move round it, but you would at once detect that it was your own motion. Just so with our annual revolution round the sun, the sun apparently passes over the stars in

succession, the stars which are in a line with the sun in summer being opposite to him in winter.

222. In the early days of Astronomy these two apparent motions of the stars were the only ones known, and in order to ascertain whether the stars were really fixed, maps of them were made, to be compared with the stars in the course of a few years, and from the comparisons made in this way no alteration of position was detected, so the ancients concluded that the stars were fixed; hence the term "fixed star," but this we shall see was an error caused by the inaccuracy of the maps.

223. When in after years a better method of fixing the positions of stars was invented, it was soon found that the positions of the stars were not always the same, and that this was occasioned by the poles of the earth changing the direction in which they pointed, just as a spinning top, before falling, whobbles; and so of course, as the positions depended on the position of the earth's axis they were found to be continually changing. Here, then, is another *apparent* change in the positions of the stars, and this apparent motion is connected with what is called the precession of the equinoxes.

224. Now that astronomers are aware of this and other motions, they expect to find a continual change in the position of stars, which they can calculate beforehand, but if the positions of stars are found after a lapse of years not to correspond with the calculated ones, after allowing for all the known

apparent motions, there must be some motion of the earth or stars which was not taken into account. But, before we go further, we will return to our boat and ship.

225. Let the ship, and the boat you are in, advance in any direction, what apparent changes will be produced in the ships on either side of you? They will appear to move in the opposite direction; those you approach will appear to get further apart, and those behind you will appear to close together, but the ships may all be moving as well as you, some in one direction, and some in another, so they all may not appear to move regularly according to our supposition; but if there is a large number visible, you would expect to find more apparently moving according to our supposition than contrary to it, their apparent motions being counterbalanced in some cases by their real motions, and in others the two motions would be added to each other, so that you could judge of your own motion.

226. This is exactly the case; it is found that in one direction the stars have a tendency to close up, and in the opposite one to open out, though, like the ships, some close up in the direction in which the majority open out and *vice versâ;* but by observing the motion of a large number of stars we are able to find that the sun, and with it of course all the planets, are steadily progressing towards a point in the constellation Hercules.

§ V.—REAL MOVEMENTS OF STARS.

227. If you saw any ship moving among the others whose motion was not accounted for on the supposition of any motion of your boat, you would at once presume that that ship had a real motion of its own. In like manner, when a star is found to move *amongst the others*, then we can safely say it has a real motion of its own; and by careful observation for a long series of years it has been discovered that a very large number of stars have what is called a **proper motion.** Arcturus, for instance, is going at about three times the rate that our earth does in its orbit round the sun, over fifty-four miles a second. From mechanical reasons it is probable that all the stars are in motion.

§ VI.—MULTIPLE STARS.

228. Not only have we such a proper motion along a path, but **some stars go round each other.** These take the name of **double** and **multiple stars** according as there are two or more moving round each other, as shown in Fig. 43.

229. They are what is called physically connected with each other, being so close that one revolves round the other, just as we revolve round the sun, but instead of the revolution being performed in a year,

the shortest known time of revolution or period of a double star is thirty-six years. Up to the present time some 800 of these systems have been discovered.

230. The distances of the stars from us is so immense that if they had planets revolving round them these would be invisible with our most powerful instruments. But it is probable that each star is the centre of a planetary system: in the case of close double stars, therefore, the planets of one star must be so near the other as to receive a considerable amount of light from it; in fact, the planets would have two suns, and, in some cases, suns giving light of different colours.

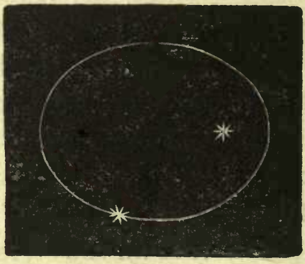

FIG. 43.—Orbit of a Double Star.

§ VII.—CLUSTERS AND NEBULÆ.

231. Besides the scattered stars of which we have been talking, there are a number of white patches in the sky like little pieces of the Milky Way, a few of

which are visible to the naked eye. When these are looked at with a telescope, some of them are seen to be very closely packed clusters of small stars; in some the separate stars are seen with telescopes of low power, while others require the highest telescopic means. Those in which the stars are easily seen are called **clusters**, while those requiring high powers to see the separate stars, and those which still appear of a cloudlike structure when the most powerful telescopes are brought to bear upon them, are called **nebulæ**.

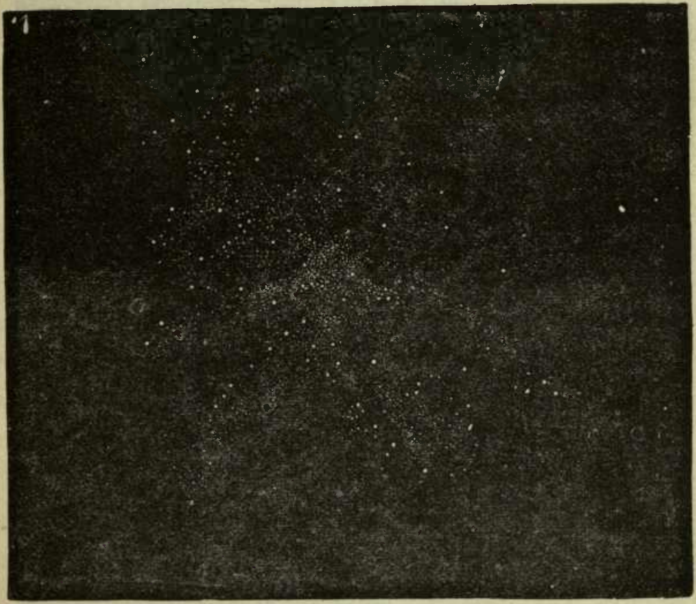

FIG 44.—The Cluster in Hercules.

232. We may therefore divide these objects into three classes: (1) the **clusters**, in which the separate stars are easily seen gradually merging into (2) the **resolvable nebulæ**; and (3) the **irresolvable**

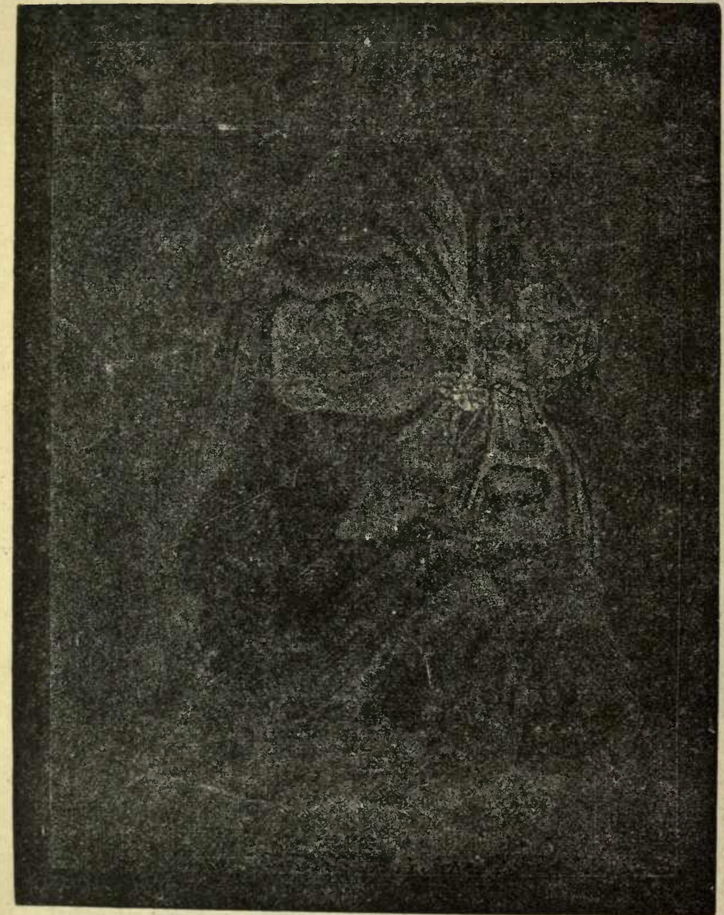

FIG. 45 —The Great Nebula in Orion.

nebulæ. The spectroscope has shown some of these latter to be of a nature different from stars or a collection of stars, and so in this they are unlike the clusters.

233. Nor is this all: not only have we cloudlike masses which may be broken up into stars, and cloudlike masses which we know cannot consist of true stars, but some stars, when closely examined, seem to be surrounded by a kind of fog, and these we know are not true stars. Such bodies are called **nebulous stars.**

234. Both the star clusters and nebulæ may from a different point of view be divided into two other classes: those which are very irregular in shape, like the Cluster and Nebula shown in Figs. 44 and 45, and those again which approach more to a globular form.

§ VIII.—THE NATURE OF STARS AND NEBULÆ.

235. I have before told you that the stars are distant suns, but you are not to suppose that all of them are *exactly* like the sun; indeed, we have evidence that they are not. Among those which are very bright, some seem to have more simple atmospheres than the sun; that is, they do not contain all the elements stated in Art. 204; and among those stars which are dimmer, and especially among those

whose light is reddish, the atmospheres seem to differ in character from that of the sun, *as if*—mark, I only say *as if*—such stars were colder than the sun.

236. Although the nebulæ appear to be very different from stars it is possible that there is a very close connection between them, for it has been thought that stars are formed by the coming together of the materials of which the nebulæ are composed, and that the planets are formed in the process. Whether nebulæ are masses of glowing gas, or clouds of stones clashing together, and thus giving rise to a luminous appearance, we do not know, but the latter view is the more probable one.

237. The idea to which I have referred, which connects nebulæ with stars and planets, supposes that a nebula in its first stage is continually getting smaller and rounder, and that when it has done so perhaps sufficiently to give rise to the appearance of a nebulous star, getting hotter all the time, it leaves behind it, round its equator, as it still contracts, rings of vapour, something like the rings of Saturn (Art. 170) which eventually break and form a globular mass of vapour, which at last forms a planet. All the time the centre is getting more dense and hot, and at last, the rate of contraction still diminishing, it shines out like a real sun, and thus goes on giving light and heat to those masses, now become cool and habitable, to which it originally gave birth. It thus shines, first, as a bright star, which afterwards becomes dim, and perhaps red, before the state of

extinction is reached to which it must surely arrive; for, do not forget, that any one mass of matter must in time cease to give out light and heat, whether that mass of matter be a coal in a fire or a star in the heaven.

VI.—HOW THE POSITIONS OF THE HEAVENLY BODIES ARE DETERMINED, AND THE USE THAT IS MADE OF THEM.

§ I.—RECAPITULATION.—STAR MAPS.

238. I must now approach a different branch of my subject. We have gone through the real motions of the earth, moon, and planets, and more recently of the stars, and the apparent motions brought about by the real motion of the earth. We have referred to the nature of nebulæ, suns, and planets, and have thus got an idea of the Earth's true place in Nature—how it is a cool body going round a cooling star, both planet and star having probably resulted from the condensation and consequent heating of a nebula.

239. I have also given you an idea of the starry heavens; how the stars—so-called fixed—have all been grouped into constellations, and lettered or numbered in the order of their brightness; and how the sun by day, and the moon and planets by night,

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are perpetually changing their places among the stars with the most perfect order and regularity.

240. I have now to ask your attention to the starry vault, considering the stars merely as things the positions of which have to be mapped; and I want to show you, first, how positions are determined, and then what use we make of them.

241. If you were clever enough, you might be able to make a sketch-map of the positions of the stars, but for astronomical purposes the positions of the stars must be known with much greater accuracy than could be attained by such a rough attempt, and even if such maps were perfectly accurate it would be very troublesome to have to refer to a star as being south of, or below, a well-known star, and to the left, or west, of another; another method of fixing their places for reference has therefore been adopted.

§ II.—POLAR DISTANCE.

242. We imagine the equator and poles of our globe extended outwards to the stars, just as their shadows would be cast by a light at the centre of the earth on the imaginary hollow globe on which the stars appear fixed (called the **celestial sphere**). The shadow of the earth's equator thus becomes the **celestial equator**, and we measure north and south to it in degrees from the shadows of the poles, calling this distance **polar distance**.

243. In this way we can say which star or which part of the sky is exactly at the pole, because it will have no motion. Get your orange and stick a pin in it at each pole; if you turn the orange round, the pin will still point to the same place. This, then, will be 0° polar distance. Now, with a telescope furnished with circles, we can find this spot in the heavens, and turning the telescope 10° from this spot (which we can easily do by means of the small circle fixed to it, because you have already seen that all circles big or little are divided into 360°, Art. 126) we can determine those stars which have 10° polar distance, then 20°, 30°, and so on, till we come to 90°, which of course marks the position of the Celestial Equator—that is, the line in the heavens which lies exactly half-way between the north and south poles, as the terrestrial equator does on the earth.

§ III.—POLAR DISTANCE IS NOT SUFFICIENT.

244. In this way, then, we can determine the polar distance of all the stars; but you will see at once that a multitude of stars may have the same polar distance, for we can stick a whole row of pins in the orange, so that all shall be the same distance from the pole of the orange marked by another pin.

245. It is necessary, then, to distinguish these apart somehow. Do not forget that the question is to

fix the position of a star. Now, to begin with, how would you fix the position of a dot on a piece of paper? Let us see. Take a sheet of paper *ABCD*, Fig. 46, and stick a pin in or make a dot *E* on it. Now let us see how we can state its position: divide the side *AD* into, say, 10 equal parts, and *AB* into, say, the same number; then on joining *EG* and *EF*, you will see that *E* is 4½ divisions from the line *AB* measured along *AD*, and is 2½ divisions from *AD* measured along *AB*, so we can fix the position to this point *E* at once with reference to the edges of the paper. So also if you were asked to place a dot at 7 divisions from *AB* and 6 from *AD*, you would draw a line *HI* from the seventh division on *AD* and another *KL* from the sixth division on *AB*, then the point *M* where they cross will be the place required.

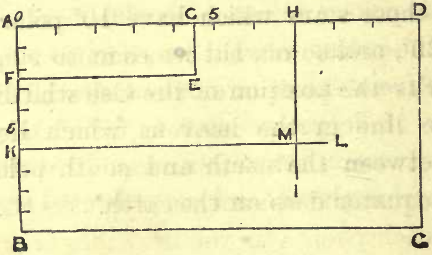

FIG. 46.—How to define the position of anything.

246. Now mark well that it is not enough to say that *E* is 4½ divisions from *AB*, because there might have been a whole line of pins or dots at that distance

from *AB*, and that it is not enough to say that *E* is $2\frac{1}{2}$ divisions from *AD*, because in like manner there might have been a whole line of pins or dots at that distance.

247. Mark well also that the moment we have two sets of measures at right angles (you have not forgotten, I hope, what that means) to each other, we can state the position of a pin or dot on our piece of paper with the greatest accuracy.

248. So it is with the stars. I have already made you acquainted with one set of measures, that which begins at the poles and measures the distances of the stars from the poles, or, what comes to the same thing, the distance from the equator, because when we know the number of degrees a star is from the pole, the difference between that number and 90° will give us the distance from the equator, as of course the equator is 90° from each pole. In the next diagram, Fig. 47, I have drawn the equator and straight lines 10° apart between it and each pole.

§ IV.—RIGHT ASCENSION.

249. Evidently therefore, to make our statement of a star's position complete, we want another line at right angles to these. Now get your orange, and stick a row of pins in it all round to mark the equator *AB* Fig. 47. Next, stick another row of pins in at right angles to the first row *CD*. This second row

will take the shape of a second circle of pins, passing over the poles of the orange, and cutting the equator in two opposite points.

250. Now the equator, and the row of pins which represents it, can only be in one place on the orange, that is, half-way between the two poles. But you may make the second circle wherever you choose, and in fact you may suppose an infinite number of such circles, all of them at right angles to the equator, all cutting it in two opposite points, all passing through the poles; of course we can imagine them 1° or 10°, or any other number of degrees apart; if we imagine them to be 15 apart, then as the heavens appear to

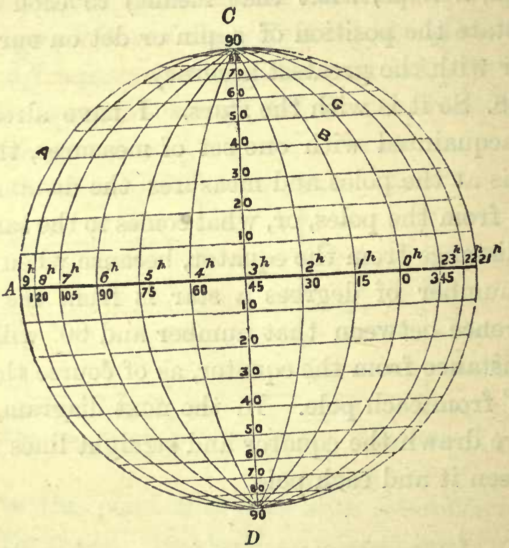
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FIG. 47.—How the positions of stars are stated.

revolve round the earth in 24 hours, one of these circles will pass over a place on the earth every hour, because $15^\circ \times 24 = 360^\circ$.

251. But we have not yet got over our difficulties. All these circles are alike ; we must therefore choose one to measure from, to represent the equator, as it were. You will perhaps think that the first will be made to pass through the brightest star. This is not so ; one of the two points of the celestial equator which lies exactly in the plane of the ecliptic (Art. 67) is chosen. This point is called **the first point of Aries.**

252. This being determined on, all the astronomer has to do is first to regulate his clock so that the stars shall appear to travel round the earth in exactly 24 hours ; to let it show $0^h\ 0^m\ 0^s$, when this imaginary circle, which passes through the first point of Aries, passes what is called **the meridian,** that is a fixed imaginary circle passing from north to south overhead, and to note the time when each star also passes it. As each star, whatever be its polar distance, passes this line, the clock, if it goes correctly, will show its distance **in time** from the first point of Aries. Thus we say that the Right Ascension of the brightest star (α) in the Bull is $4^h\ 28^m$; of the brightest star in the Virgin, $13^h\ 18^m$, and so on.

§ V.—RECAPITULATION.

253. If you have understood this you will know that the place of a star is stated or defined :—

First—By its distance in degrees from the pole. This is called its **polar distance**; from which (as stated in Art. 249) we can easily determine its distance from the equator, called its **declination.**

And *Secondly*—By its distance in time from the great circle which passes through the first point of Aries. This is called its **Right Ascension.**

254. The positions of all stars have thus been determined, and **further, we can calculate what position among the stars the sun, moon, or any of the planets will occupy at any instant of time.**

255. This is one of the most useful results of Astronomical Science, for it enables us to map the surface of the earth, and also enables the traveller in the trackless waste, or the mariner out of sight of land, to find out exactly where he is on that surface.

§ VI.—THE LATITUDE OF PLACES ON THE EARTH.

256. Let us see then how we can fix the position of any place on the earth. If you were asked to tell any one where a neighbouring town or village was,

you would probably say, so many miles away, and along a certain road, or in a certain direction, say S.W. of your house. This answers very well for short distances, but it would never do to refer all places to this distance and direction from your house, or from any other one place. If the earth were flat we could use the method referred to in Art. 246, but as the earth is not flat, we do this: we measure from the equator towards the pole in either hemisphere, and if you refer to a globe you will see that there is a number of circles drawn at equal distances apart between the poles and the equator. These circles are called **parallels of latitude.**

257. Remember, that the positions of the heavenly bodies have been determined with reference to the earth's pole and by means of its rotation. Now, if you will think a little, you will see that if there were a star known to be of 0° north polar distance, that star would be exactly over your head if you were at the north pole, **and therefore you would know you were at the pole if that star appeared fixed exactly over your head.** If there were a star known to be of 90° polar distance, that star would be exactly over your head if you were at the equator; and therefore **you would know that you were at the equator if that particular star passed over your head.**

258. Similarly, for any place north or south of the equator, we can determine the distance in degrees of that place from the equator, by observing which star,

or other heavenly body the declination (Art. 253) of which is known, passes overhead. And this is the meaning of the Equator, and of the circles parallel to it, you see in maps and globes. An observation, the principle of which I have stated, must have been made before the positions of any places were laid down. Thus, in maps, you will find the distance of London from the equator shown as $51\frac{1}{2}°$ N., because the star γ Draconis, with a north declination of $51\frac{1}{2}°$, passes exactly over London.

259. This distance from the terrestrial equator is called **latitude**, the distance from the celestial equator being called declination (it is a pity that the same word is not used for both), and we have of course **N. and S. latitude**, as we have N. and S. declination.

260. The latitude of a place can also be determined by the apparent altitude of the pole star above the horizon, just in the same way as the rotundity of the earth is determined. The observer at the equator sees the north polar star on his horizon, its altitude is then 0°, but if he goes about $68\frac{1}{2}$ miles north it is 1° above his horizon, his latitude is said then to be 1°, and so on, gradually increasing up to 90° at the poles. So if we at any place, or time, measure the altitude of the pole star, we at once get our latitude and can then fix our position on a map or globe.

261. We have imagined such a pole star for these observations for the sake of simplicity, but in reality there is no star absolutely at the pole, what is called

the pole star being about $1\frac{1}{2}°$ from it, so that allowance has to be made for this.

262. It will be clear to you that, for the same reason that a large number of pins on your orange can be at the same distance from the pole of the orange, and a large number of stars may have the same polar distance, so a large number of places on the earth may have the same latitude. Thus, Naples has nearly the same latitude as Pekin and New York.

§ VII.—THE LONGITUDE OF PLACES ON THE EARTH.

263. To determine finally, then, the position of a place on the earth's surface, we want something else which shall do for the earth what **right ascension** does for the heavens. This something else is called **longitude.**

264. To accomplish this, geographers imitate astronomers; they imagine a circle belting the earth, cutting the Terrestrial Equator at right angles, at two opposite points, and passing through the poles of the earth; and they measure from this circle.

265. You will naturally ask where this is. It really does not matter where this start-point is taken; so, as a matter of fact, each principal nation of the world uses a different one, taking that which passes along the spider line which marks the centre of one of the chief instruments in the Central Observatory.

In England, for instance, we reckon from the circle which passes through the Greenwich Transit Instrument. In America they reckon in the same way from Washington Observatory: in France from the Paris Observatory, and so on.

266. The next question is, *how* do they measure? The position of a place on the earth, east or west of the circle which passes through the real Greenwich, is determined in exactly the same manner as the position of a star is determined east or west of the circle which passes through the imaginary first point of Aries. **It is a question of time.**

267. To prove this, let us again use the orange and knitting-needle. Represent the circle passing through the poles and Greenwich by a row of pins. Let each pin represent an observer with a watch showing the time of the Greenwich clock, and let one of them represent the observer at Greenwich; let a candle or lamp represent a star, and rotate the orange from west to east, as shown in Fig. 9, to represent the motion of the earth. The line of pins will all come between the candle and the knitting-needle at once. Therefore, all the watches of our imaginary observers will note the passage of the imaginary star at the same moment.

268. So that all places exactly north or south of Greenwich will have the same start point of time as Greenwich itself; in other words, they will have the same longitude.

269. Now take out the pin representing Greenwich,

and put it to the west of the row of pins. As the orange must still be moved from west to east, it is clear that this pin will come between the lamp and the knitting-needle after the row has passed; that is, there will be a difference in the times at which the row of pins and the solitary pin pass the lamp, since all the watches are set to Greenwich time. Let us suppose that at the row of pins the Greenwich time is 1^h; then it is clear, that as the pin representing Greenwich passed under the lamp afterwards, the clock at Greenwich itself indicated some time after 1^h, let us say it was 2^h. Then there is a time difference of one hour between the two places, and all the places of the same longitude represented by the row of pins will be shown to the east of Greenwich.

270. Now let the lamp represent the sun. The sun brings local time to a place, because it is 12 o'clock (near enough for our present purpose) at a place when the sun is south or crosses the meridian at midday. If therefore I have this local time and Greenwich time as well, I can tell first whether I am east or west of Greenwich, and then how far east or west. If when with me it is 10 A.M. it is 12 (noon) at Greenwich, then I am situated to the west of Greenwich, and the earth must turn for two hours before I am brought under the sun; if it is 2 P.M. with me when it is 12 (noon) at Greenwich, then I am to the east of Greenwich, as I passed under the sun two hours ago. Such a difference of time of 12 hours = 180°; of 6 hours = 90° east or west; of 3 hours, 45° east or west, and

so on; so that it is immaterial whether we reckon longitude in degrees or hours, for since there are 360 degrees or 24 hours into which the equator is divided, each hour corresponds to 15°. We also express the longitude of a place by its distance **east of Greenwich** in hours, so instead of calling a place twenty-three hours west it is called one hour east.

271. In practice a difficulty arises in finding out at a distance from Greenwich the exact time at Greenwich. A great number of ways have been tried, in order to let it be known at one observing station what time it is at the other. Rockets have been sent up, guns fired, fires lit, and all kinds of signals made at fixed times for this purpose; but these, of course, only answer for short distances, so for long ones carefully-adjusted chronometers had to be carried from one station to the other, to convey the correct time; but now, when telegraph wires are laid from one place to another, as from England to America, it is easy to let either station know what time it is at the other. For ships at sea chronometers answer well for a short time, but they are liable to variation.

272. There are certain astronomical phenomena whose instant of occurrence can be foretold, and which occur so far away from the earth that they are visible over a great part of its surface at the same moment of time; these are published in the Nautical Almanacs, such as the eclipses of Jupiter's moons, and the position of our own moon. Suppose that an eclipse of one of Jupiter's moons is to take place at 1 P.M. Greenwich

time, and it is observed at a place at 2 P.M. of their local time, *i.e.*, two hours after the sun had passed the meridian, then manifestly the clock at Greenwich is at 1 P.M. while theirs is at 2 P.M., and the difference of local time is one hour, and the place is one hour or 15° east of Greenwich. If, however, the eclipse was observed at 12 noon, then the place must be one hour west of Greenwich.

VII.—WHY THE MOTIONS OF THE HEAVENLY BODIES ARE SO REGULAR.

§ I.—WHAT WEIGHT IS.

273. We have just seen that the stars are so useful to man because we can exactly calculate in what part of the heavens they will be at any future time. Now of course if their motion or our motion were irregular, this could not be done. Before I complete my task then I must attempt to explain to you how it is that we are enabled to foretell the movements.

274. This brings us to the more mechanical part of Astronomy, the laws of the motions of the heavenly bodies. The ancients believed the earth to be at rest and the sun and planets to revolve round it. This idea, however, gave way for the correct one which has been stated, and then came the question, Why do they so revolve? It was first supposed that the planets were carried round in a vortex or whirlpool of some

kind; and it was afterwards shown that the planets revolve round the sun and the moons round their primaries, not exactly in circles, but what are called ellipses, having the sun not quite in the centre. Newton showed that on mechanical principles they ought to do so, and I must try to show you why.

275. You have doubtless often seen a ball or stone thrown up in the air and fall again to the earth. Did you ever ask yourself the question, Why does it fall? Probably not; but if you were asked you would probably answer, "Because all things that are heavy fall to the earth;" and so you would get out of the difficulty, but only to get into another. Why are things heavy? is the next question. The answer is, that **all substances attract each other in the same manner as a magnet attracts iron**; so one stone attracts another stone, but with very small force, and the earth being an immense mass of different substances attracts all things on it with such a force that the attraction of one stone on another is inappreciable in comparison.

276. The weight or gravity therefore of anything only means the force with which the earth attracts it, and causes it to gravitate towards itself.

277. Now the attractive power of bodies is in proportion to the amount of matter they contain. For instance, if the earth were doubled in size, still being made of the same materials, it would attract everything on it with double the force it now does, and consequently everything would weigh double its

present weight—so that then our legs would have to carry as much weight as if there were a person on our back continually. Also if we double the quantity of matter attracted by the earth, the force with which it is attracted, or its weight, is also doubled. For instance, a pint of water weighs one and a quarter pounds, two pints therefore weigh two and a half pounds.

278. I have before (Art. 135) made use of the words **quantity of matter or mass.** A pint of lead contains a greater quantity of matter or has a greater mass than a pint of water, and the word mass is practically only another word for weight so long as we are on the earth; but a pound weight here would weigh over two pounds at Jupiter, although the quantity of matter or mass is unchanged. So in dealing with the weights of bodies under different attractions we must use a word expressing a constant quantity of matter.

279. If our earth were doubled in size, a pound weight would still balance another pound weight in the scales, for both would have their weights increased really to two pounds; so we must use some other means to determine any alteration of the force of gravity.

280. A spring can be arranged so as to answer the purpose, as it is not altered in any way by gravity; but the most accurate method is to ascertain the distance through which a body falls to the earth in a certain time, usually one second, since the greater the

attraction the quicker will be the fall; at the surface of the earth a body will fall, in a vacuum or space without air to resist it, 16 feet in one second, and at the end of that second its velocity is 32 feet a second, —that is, if the force of gravity ceased at the end of the second it would go on through 32 feet in the next second.

281. The force of gravity at the earth's surface is therefore represented by 32. On the surface of Jupiter the force of gravity is $2\frac{1}{2}$ times that of our earth and is represented by 78, meaning that in one second a body allowed freely to fall would attain a velocity of 78 feet a second.

§ II.—GRAVITY DECREASES WITH DISTANCE.

282. I have already told you that the weight of anything on the earth means the force with which the earth attracts it. I have now to add that this force is not the same for bodies at different distances from the earth.

283. Those of you who have had a magnet in your hands have probably noticed that pieces of iron are attracted the more strongly the nearer they are to the magnet; this is easily seen by laying a needle on the table and sliding a magnet towards it, when you will see that at a distance of a few inches the needle is not attracted with sufficient force to overcome the

friction of its rolling on the table, and the magnet has to be moved nearer to it until the force is sufficient to overcome the resistance, when the needle rushes to the magnet.

284. It is just the same with gravitation, the further a body is away from the earth the less it is attracted; and Newton found that the force of gravity at double the distance was not half, but half of a half, or one quarter; at three times not a third, but a third of a third, or one ninth, and so on; so if the distance be increased to eight times, we have to multiply eight by itself, or what is called square it, making 64, and placing 1 over it, making $\frac{1}{64}$ showing that the attraction at eight times the distance is only one sixty-fourth of what it was originally.

§ III.—HOW THIS EXPLAINS THE MOON'S PATH ROUND THE EARTH.

285. Newton tested this by the motion of the moon in the following manner: The moon, as we have already found, revolves round the earth; but we have not seen yet why it should do so. Now, however, we are prepared to find that it is held in its nearly circular orbit by the attraction of the earth acting on it as a sling does on the stone, preventing it from flying off, as it would do if the string of gravity were cut, just as the stone flies away in a straight line when the sling is released.

286. Let us consider this with the help of the

diagram, where *E* represents the earth and *MBA* the orbit of the moon; and let us suppose the moon to be at *M;* then if gravity ceased to act, the moon would continue on in the same straight line that it was moving in at the time gravity ceased to act, and would go on towards *N;* and in one second it would get, say to *M′*, but by the action of gravity we find the moon actually at *B*, showing that the earth's attraction has had the effect of drawing it from *M′* to *B*, and since we know the dimension of the moon's orbit, it is only a matter of calculation to find the distance from *M′* to *B* through which the earth draws the moon in one second, which is a little under one-eighteenth of an inch.

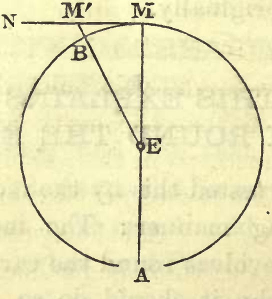

FIG. 43.—The fall of the Moon towards the Earth.

287. Let us see if this fact falls in with Newton's idea. What distance ought a body to fall, or be attracted through in one second, at the distance of the moon? The moon is 240,000 miles from the earth roughly, and the surface of the earth is 4,000 miles from its centre, at which point we can consider the

whole attraction concentrated, and 4,000 into 240,000 goes sixty times, so that the moon is just sixty times further from the earth's centre than the surface is; and the attraction there should be sixty times sixty, or 3,600 times less at the moon's distance; but the force of gravity at the surface of the earth is such that bodies fall sixteen feet a second, so at the distance of the moon they should fall $\frac{1}{3600}$ of sixteen feet or one-eighteenth of an inch, which as we have seen is the observed amount.

§ IV.—THE ATTRACTION OF GRAVITATION.

288. In this way Newton discovered that the very same force that draws a stone to the earth, called the *attraction of gravitation*, keeps the moon in her path round the earth. Nor did the discovery end here; he showed that the earth and all the other planets were thus kept in their orbits round the sun; and that the same law of gravitation holds good with the most distant star. All the apparently irregular motions of the heavenly bodies have been reduced to law and order by Newton, who showed that all the motions were really regular, and therefore could be calculated beforehand. He thus enabled mankind not only to admire the divine beauty and harmony of the universe in which we dwell, but to make use of the motions of the heavenly bodies for purposes of daily life.

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